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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JET PROPULSION LABORATORY 1966 ANNUAL REPORT
CALIFORNIA INSTITUTE OF TECHNOLOGY

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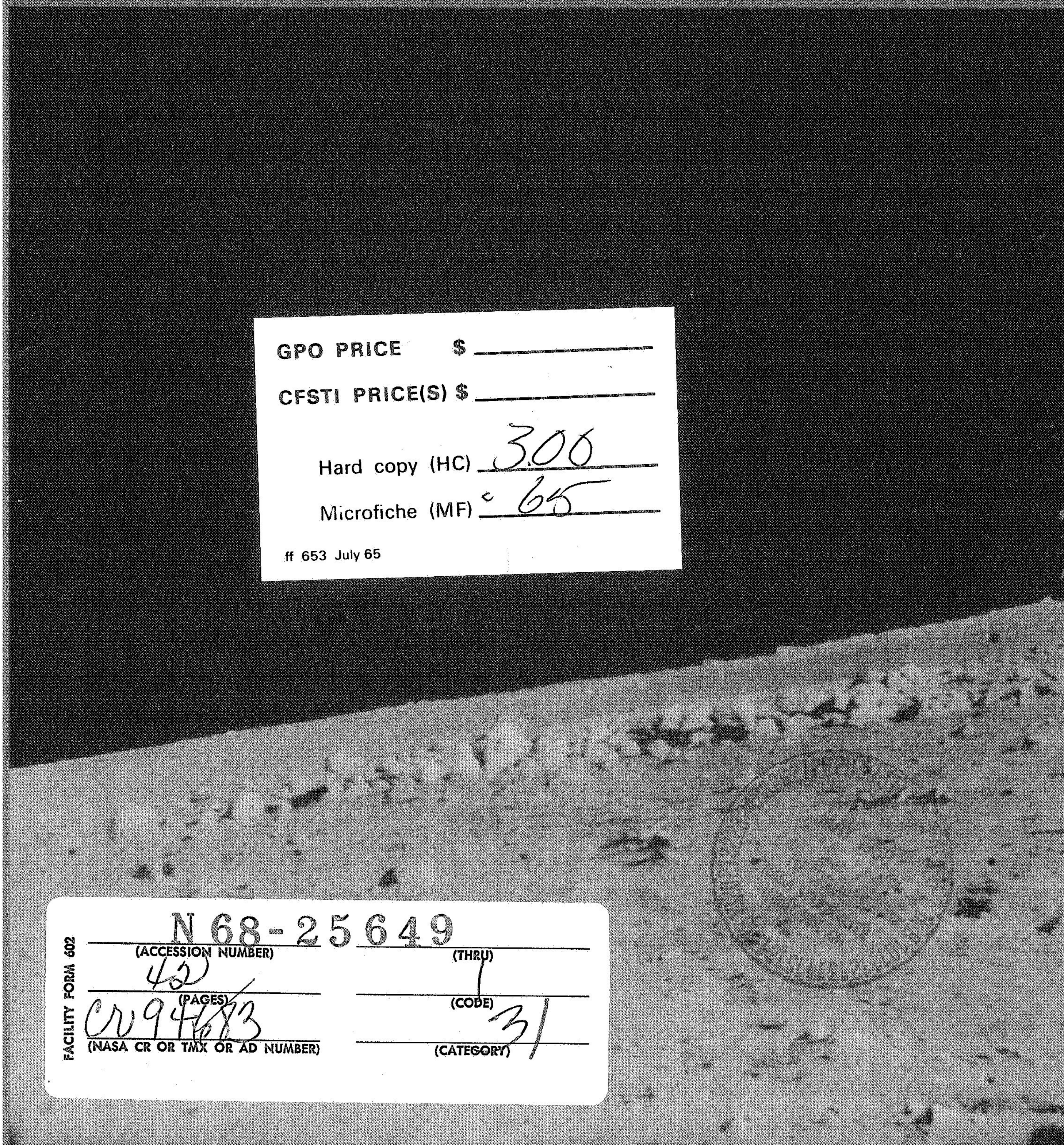

A description of work accomplished under Contract NAS 7-100 between the California Institute of Technology and the National Aeronautics and Space Administration for the period July 1, 1965, to December 31, 1966.

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FRONT COVER: Lunar landscape photographed by Surveyor I on June 13, 1966. Near edge of the rock field is about 150 meters from the spacecraft. Rocks are on the rim of a large crater.

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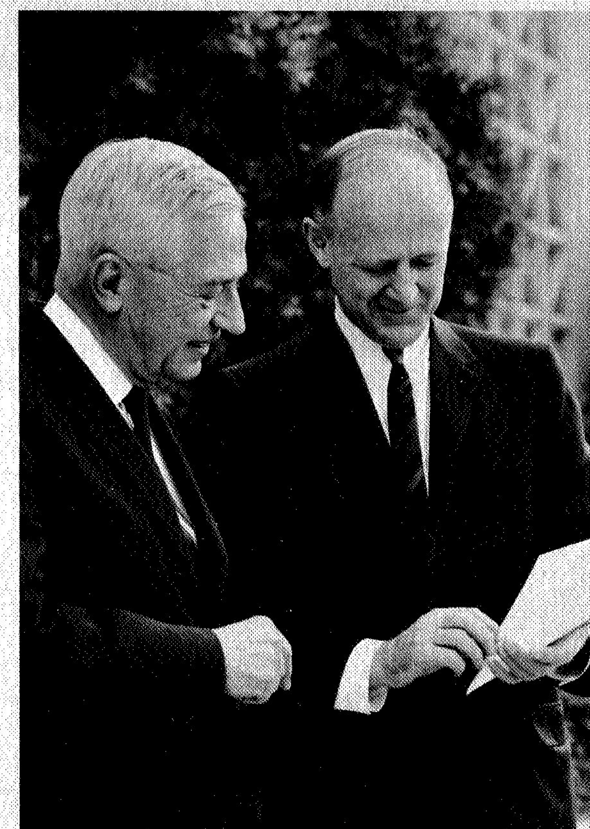

The year 1966 was the Laboratory's twenty-seventh — a busy year marked by successful achievement and continued operations in the lunar and planetary flight programs, a significant addition to the Deep Space Network facilities, implementation of new planetary flight projects, and continued planning for advanced planetary missions, research, and the development of scientific instruments for space applications.

The successful landing of Surveyor I on the lunar surface, followed by a program of photographic investigation, yielded many valuable data on the nature and form of the lunar surface in fine detail. The Laboratory also conducted space flight operations for two Pioneer missions, two Lunar Orbiter missions, and two Atlas/Centaur test flights, and maintained contact with Mariner IV through its second year of operation. Completion of the 210-foot Advanced Antenna System at the Mars Station in Goldstone permitted the Deep Space Network to recover Mariner IV telemetry many months earlier than expected.

The Mariner Venus '67 Project, scheduled for a single launch in June 1967, completed spacecraft modification and conducted a number of qualification tests during the year. Mission and system design efforts for the Mariner Mars 1969 project were also carried out. A number of studies and considerable advance planning associated with possible future Mariner-class missions and the Voyager 1973 Mars landing were conducted. Work on several scientific-instruments associated with other space flight missions and technology developments in all relevant fields is also under way.

Thus, the Laboratory continued during 1966 to pursue on a broad front the exploration of the solar system, the supporting art and technology, and the related sciences.

W. H. Pickering

W. H. Pickering
Director

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SURVEYOR

In the difficult and chancy exploration of space, it is rare that a first mission flown by an unmanned spacecraft achieves all its objectives—and more. The brilliantly successful flight of Surveyor I was all the more notable because it incorporated many operationally new elements. Among these were the Centaur high-energy, hydrogen-fueled rocket serving as the second stage of the launch vehicle, three throttleable vernier rockets, extremely sensitive velocity- and altitude-sensing radars, and an automatic closed-loop guidance and control system that, in the terminal phase of the flight, precisely steered and decelerated the spacecraft to a soft landing. Finally, there was the survey television that . . . sent back more than 10,000 pictures of high scientific content.

That these and scores of other complex subsystems performed exactly as designed is testimony to the skill, imagination, and dedication of the thousands of people who brought about this extraordinary achievement. It is also testimony, in a broader sense, to the Nation's steadily mounting proficiency in the design, testing, and flight of space vehicles.

HOMER E. NEWELL, ASSOCIATE ADMINISTRATOR FOR SPACE SCIENCE AND APPLICATIONS,
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, JUNE 17, 1966.

Surveyor I

The lunar landing of Surveyor I, some 35 miles north of the crater Flamsteed in Oceanus Procellarum on June 2, 1966, marked the first successful U.S. soft landing of a remotely controlled spacecraft on the moon.

Surveyor I was launched from Cape Kennedy, within 1 second of its planned launch time, at 14:41:01 GMT on May 30, 1966, on a direct-ascent lunar trajectory. The performance of the Atlas/Centaur launch vehicle was near perfect, and the spacecraft was placed on a flight path that would have resulted in an uncorrected landing on the moon within 250 miles of the aim point. During cruise flight, Surveyor obtained attitude references from the sun and Canopus sensors and from gyroscopes; small cold-gas thrusters provided attitude control.

Shortly after spacecraft separation, two-way communications lock was achieved by the Deep Space Station at Johannesburg, South Africa. At this time, control of the flight was transferred from the Eastern Test Range to the

OPPOSITE: *Surveyor I photographs its own shadow on the lunar surface.*

Space Flight Operations Facility at JPL, from which all commands originated to the spacecraft for the remainder of the mission. Hughes Aircraft Company, which designed and developed the spacecraft, participated with JPL in the conduct of the mission. At 0645 GMT on May 31, 1966, a midcourse correction was executed, using the three liquid-fueled vernier propulsion engines, following which the spacecraft was commanded back to its cruise attitude.

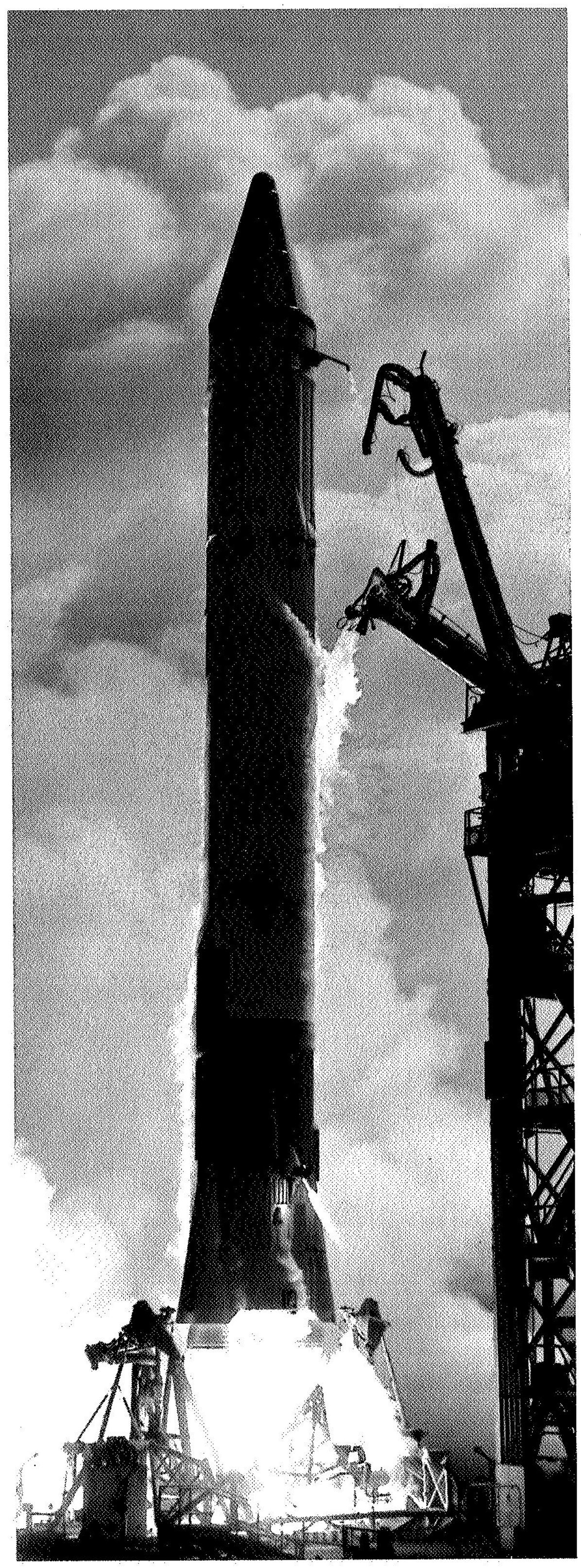
As Surveyor approached the moon, about 63 hours after launch, the spacecraft main retro rocket thrust axis was aligned along the flight path. At an altitude of 46.75 miles, main retrorocket ignition took place. After a 40-second burn and jettisoning of the empty rocket case, Surveyor I was close enough to the moon to receive an excellent return from the radar altimeter and Doppler velocity sensors. The radar signals were processed by the on-board computer and autopilot to control the three vernier rocket engines, steering and decelerating the spacecraft in a predetermined descent profile. Finally, at an altitude of about 14 feet, the vernier engines were cut off and, at 06:17:37 GMT on June 2, 1966, Surveyor landed gently on the surface of the moon, within about 9 miles of the aiming point established at the time of the midcourse correction.

The three footpads contacted the surface nearly simultaneously (within 19 milliseconds of each other) and penetrated to a depth of a few inches. The spacecraft then rebounded approximately 2½ inches above the surface before finally coming to rest.

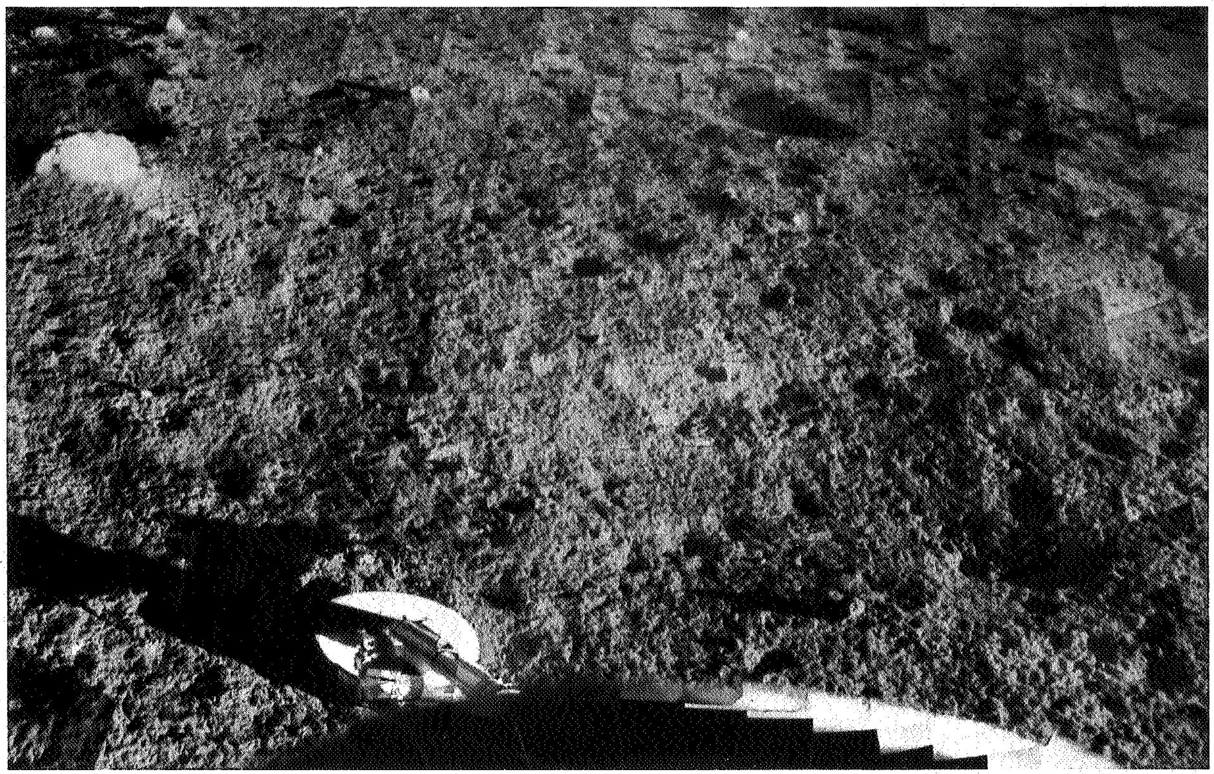
Over 100,000 commands were sent, verified, and executed without error during the mission. Of these, approximately 290 commands were transmitted during the transit phase.

Surveyor I satisfied all mission objectives. The responsive performance of the entire system resulted in good engineering data being yielded in all categories. More than 11,000 television pictures were returned from shortly after touchdown on June 2, 1966, until July 14, 1966, the end of the second lunar day. The spacecraft was subsequently interrogated on the fifth, sixth, and eighth lunar day.* Although no additional television pictures were obtained, considerable engineering performance data were derived from these interrogations.

In addition to having demonstrated that a spacecraft launched from earth can make a soft landing and operate



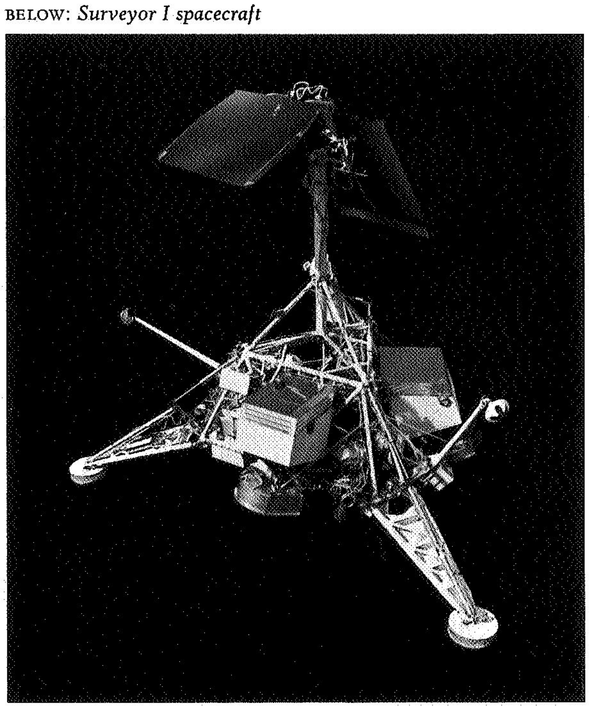
* 1 lunar day = 14 earth days.



Lunar surface mosaic composed of overlapping individual pictures. Spacecraft shadow is evident at lower left.

OPPOSITE: *Surveyor I launch on May 30, 1966*

BELOW: *Surveyor I spacecraft*



for several months on the lunar surface, Surveyor I provided much valuable data on the moon's equatorial environment. Photographs of impressions made by the spacecraft's footpads and blocks have, for example, indicated that the landing area is composed of a material which is quantitatively similar to damp, fine-grained terrestrial soil. Sensor data obtained during touchdown show that the relatively smooth surfaces in Oceanus Procellarum have enough bearing strength to permit a safe landing by Project Apollo astronauts. Celestial objects were photographed, including Sirius, Canopus, Jupiter, and Gemini.

Among the photographs from Surveyor I are several showing the sun's corona out to at least three or four solar radii. These pictures have precipitated special interest because they indicate the possible scattering of sunlight from a lunar atmosphere.

It is of interest to note that the Ranger pictures represent an improvement, by three orders of magnitude, over the best resolution of the lunar surface achieved by earth-based photographs, and that the Surveyor pictures represent a gain by an additional three orders of magnitude over the highest-resolution Ranger pictures.

Years may pass before studies of lunar data will finally resolve such questions as that concerning the volcanic and/or meteoritic origin of the moon's craters. However, Surveyor I has already confirmed many observations and theories regarding lunar topography, temperatures, and radar cross section.

Surveyor II

The second Surveyor flight, which initially gave every appearance of success, was terminated in the morning of September 22, 1966. The spacecraft and all other instruments performed nominally up to execution of the midcourse thrust maneuver. At that point, the data indicate that vernier engine 3 failed to ignite, and the resulting imbalance of thrust from engines 1 and 2 imposed a tumbling motion on the spacecraft from which it failed to recover. Subsequent endeavors to fire the vernier engines increased the tumbling rate. After many hours of attempting recovery without success, it was decided to obtain additional engineering data on the performance of the various spacecraft subsystems. This sequence culminated in a simulation of the terminal descent sequence. The main retro was ignited, and approximately 30 seconds later, contact was lost with Surveyor. All subsystems except for vernier engine 3 appeared to function properly. Following continuous receiver search for the spacecraft with no results, the mission was terminated. Engineering data of considerable value were derived from this flight, which have contributed corrective guidance for future Surveyor missions.

Future Missions

As noted in last year's annual report, initially the Surveyor Project included seven approved Block I missions and three approved Block II missions. The Block I missions were to consist of four flights designed to gain engineering test experience and three to acquire limited scientific data. The three Block II missions were to provide for more extensive exploration of the lunar surface. In early 1966, the Block II series was cancelled and, in mid-1966, as a result of the success of Surveyor I, Block I was reprogrammed to two engineering missions, followed by five enhanced scientific data-recovery missions. Current plans provide for an extended scientific payload program with simplified surface samplers on the next two spacecraft and alpha-scattering instrumentation on the final three.

MARINER

The Mariner Program, which counts among its accomplishments the first successful flyby of the planet Venus by Mariner II in 1962 and the unique photographic Mars mission of Mariner IV three years later, plays a vital and continuing role in the exploration of the solar system.

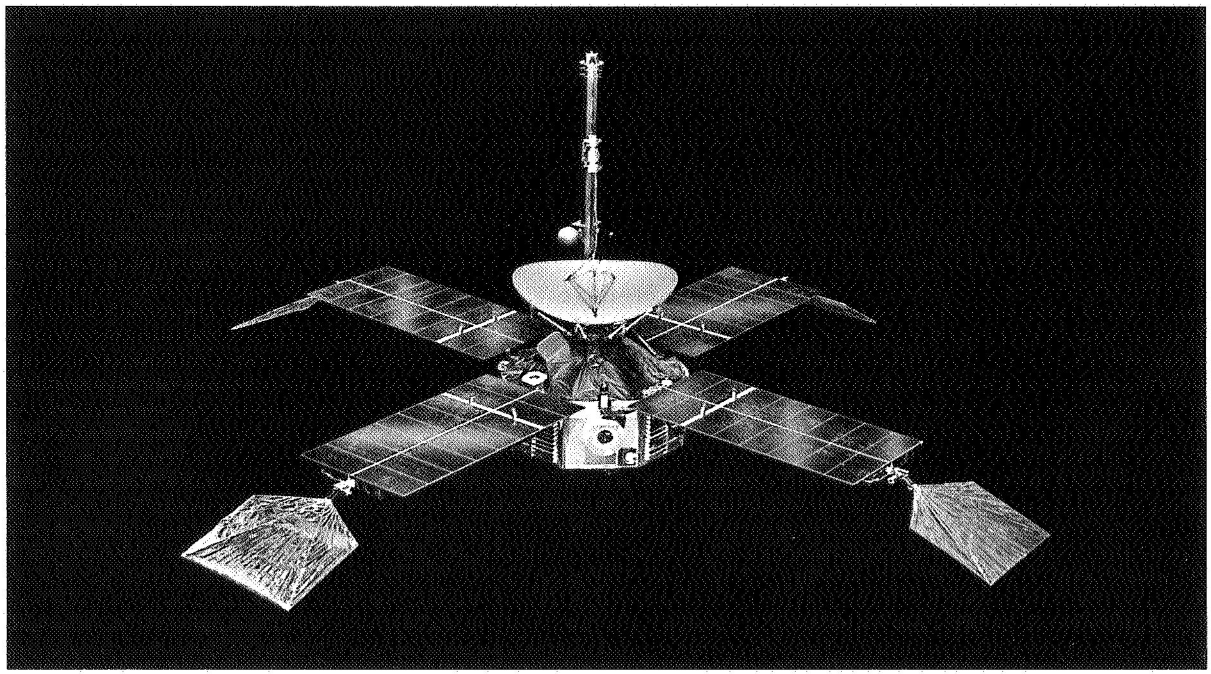
The Mariner missions are based on the use of unmanned deep space probes designed to investigate the basic characteristics of the planets and to explore the interplanetary environment. Adaptable to the intermediate class of launch vehicles such as the Atlas/Centaur, the spacecraft are capable of flying by, orbiting, and placing probes on planets; all are fully attitude-stabilized vehicles, capable of changing and maintaining orientation on command, precision-correcting the trajectory, aiming instruments at planetary targets, converting solar energy to electrical power, and communicating over extreme distances through earth-oriented high-gain antennas. One of the principal benefits of the Mariner Program is the capability of performing precursor missions to larger unmanned missions and eventual manned flight to the planets. These efforts continue to develop the technology, the equipment, and techniques involved in the construction of spacecraft for long-distance, long-duration unmanned spaceflights and the sterilization techniques required for planetary entry and landing.

Attractive Mariner missions have been designed to place probes into the atmospheres of Venus and Mars beginning with the 1970's, to employ gravity assist techniques to fly by two planets such as Venus and Mercury in 1973 with a single spacecraft, and to penetrate to the comets.

Mariner IV

On July 14, 1965, Mariner IV flew within 6200 miles of the planet Mars. The spacecraft was the first to make scientific measurements in a region of interplanetary space considerably beyond the earth's orbit. These measurements not only confirmed the phenomena discovered during the Mariner II flight to Venus but also increased confidence in the technology required to fly in an interplanetary environment.

Prior to Mariner IV's successful flyby of Mars, there was considerable uncertainty about the radiation environment near the planet. As a result of the mission, it was determined that there is no magnetic field about Mars and that the planet is therefore subjected to the direct bombardment of cosmic rays and solar plasma. Studies of its



Mariner IV spacecraft

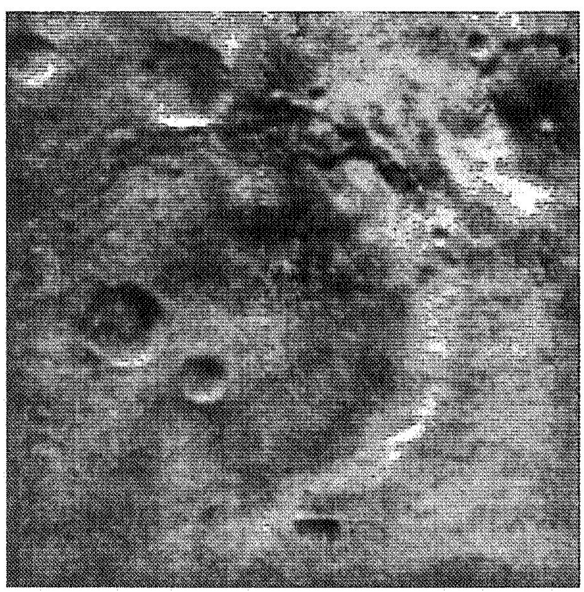
ionosphere will be of definite aid in the understanding of various phenomena in the ionosphere of the earth.

The data obtained in the occultation experiment far exceeded all expectations. Subsequent analysis has provided accurate values for the critical characteristics of the Martian atmosphere such as the presence and intensity of the ionosphere, the surface pressure, and the scale height. The information yielded by the occultation experiment is extremely important in defining the entry and landing requirements for future surface exploration vehicles.

The unprecedented photographs of the Martian surface taken by Mariner IV (a total of 21 complete pictures and a partial one) show that the planet is covered with craters quite similar to those on the moon. Since the craters show very little evidence of erosion, it is unlikely that Mars has had a significant atmosphere or significant amounts of water in well over a billion years.

The photographs present no evidence of volcanic activity, which would indicate that the planet has no internal stress such as would be caused by the molten core of the earth. This apparent lack of internal stress is consistent with the absence of a detectable magnetic field around Mars.

Although the photographs of Mars are indeed spectacular, it is generally agreed that they leave open the



Picture 11, taken by Mariner IV, distinctly shows craters on the surface of Mars.

question of whether life exists or has ever existed on Mars. The information obtained from the photographs has, however, increased our understanding of the planet and has significantly contributed to the design of photographic equipment for future missions.

Mariner IV presentation at the White House. From the left: W. H. Pickering; Oran W. Nicks, Lunar and Planetary Programs Director for NASA; J. N. James, JPL Assistant Laboratory Director for Lunar and Planetary Projects; President Johnson; James E. Webb, Administrator, NASA.

On October 1, 1965, the Mariner Mars 1964 Project was officially concluded. The spacecraft transmitter was switched from the high-gain to an omnidirectional antenna, and Mariner IV became a radio-frequency signal source used to explore new communication techniques at record distances far in excess of the 134 million miles attained at encounter.

The continued journey of Mariner IV around the sun provided an opportunity to perform a radio propagation experiment through the solar corona. Through the use of the new 210-foot antenna at Goldstone, California, considerable data on the effects of radio-frequency signals passing through the solar corona were obtained.

In the year since the official end of the mission, additional telemetry recordings have been taken on thirteen different passes. After a lifetime of 2½ years and some 1.13 billion miles of space travel, the total operating time accumulated by Mariner IV, with apparently normal performance of the spacecraft, was in excess of 18,000 hours.

Concurrently, with the approval of the Mariner Venus 1967 Project, NASA approved a plan for the reacquisition of the Mariner IV spacecraft, so that scientific data retrieval could be accomplished in a formal operational manner. These operations are to commence early in 1967 and will be performed in conjunction with the Mariner Venus 1967 mission.

The primary objective of these new Mariner IV activities is to obtain additional scientific information on the interplanetary environment in a region of space further from the sun than the orbit of earth during a period of increasing solar activity. The secondary objectives are to obtain additional engineering knowledge about the consequences of extended exposure of spacecraft equipment to the interplanetary space environment and to acquire experience in the operation of a spacecraft after a prolonged lifetime in deep space.

Mariner Venus 1967

A project for a Mariner-class mission to Venus was established in December 1965. The primary objective of the mission is to conduct a flyby of the planet in 1967 to obtain scientific information that will complement and extend the results obtained by Mariner II in 1962 and is relevant to the determination of the origin and nature of Venus and its environment. Secondary objectives are to acquire engineering experience in converting and operating a spacecraft initially designed to go to Mars into one suitable for Venus, and to obtain information on the interplanetary environment during a period of increasing solar activity.

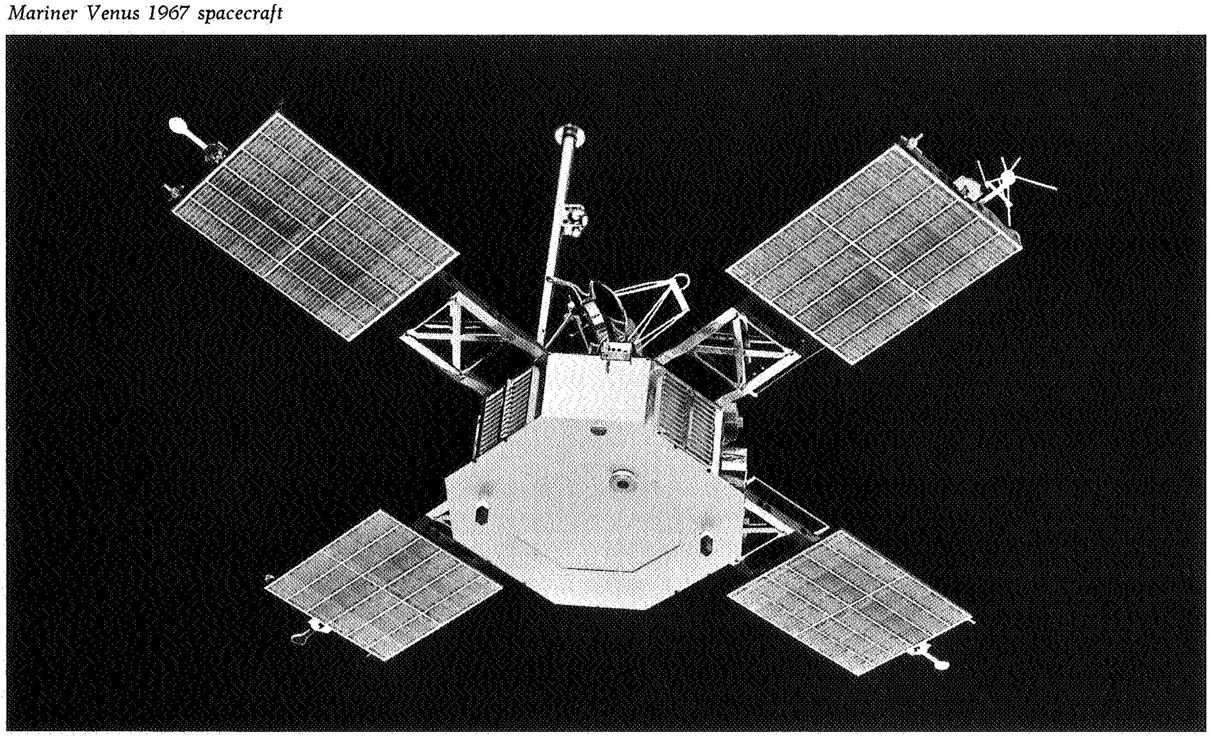
The 5-month cruise of the spacecraft, from launch to encounter, will provide an outstanding opportunity to observe the effects of solar activity and will also permit, for the first time, the correlation of data from a number of spacecraft located at widely different distances from the sun (i.e., earth satellites and Pioneer and Mariner spacecraft).

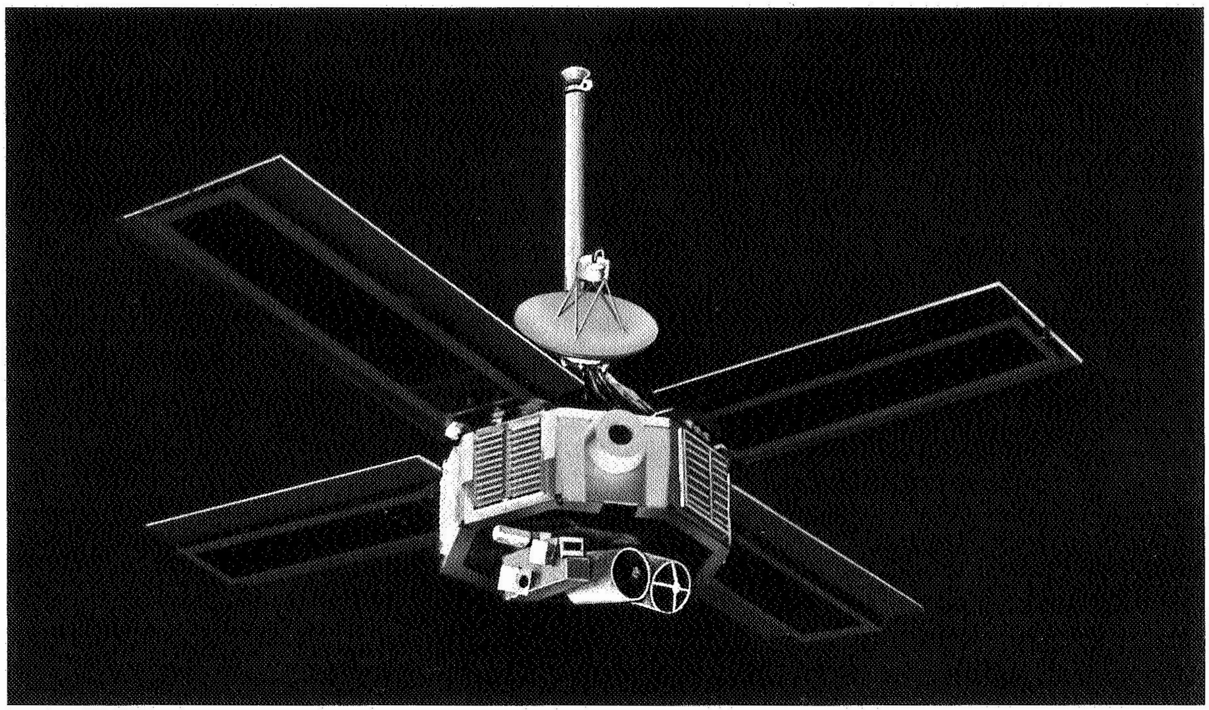
Because of the marked differences between the Mariner Venus 1967 mission and the Mariner Mars 1964 mission, it was necessary to alter the design of the existing spacecraft. The solar panels were rotated 180 degrees, and the panel area was reduced; the tape recorder was modified; and a new data-automation subsystem was selected. To accommodate the earth occultation experiment using the spacecraft radio signal, a means for deploying the high-gain antenna was installed on the spacecraft. The Mariner Mars 1964 proof-test model was dismantled, and tests were run to determine the degradation caused by prolonged storage. The configuration of the new spacecraft preserved the proven guidance and control techniques. The spacecraft will be fully attitude-stabilized, use the sun and Canopus as reference objects, and be capable of performing two trajectory correction maneuvers.

Certain science instruments used on the Mariner Mars 1964 mission were eliminated, among them the TV and its associated scan platform, the cosmic dust detector, the cosmic ray telescope, and the ion chamber. The remaining science complement, consisting of the trapped radiation detector, the helium magnetometer, and the solar plasma probe, was supplemented with an ultraviolet photometer and a dual-frequency receiver. These instruments will monitor and measure solar cosmic rays and energetic electrons in interplanetary space, search for magnetically trapped particles in the vicinity of Venus, provide further information about the Van Allen radiation belt around the earth, and determine the magnetic field of Venus. They will also take measurements of the interplanetary magnetic field, and obtain information about the boundary between the interplanetary and planetary fields, measure the intensity of low-energy protons ejected from the sun, determine the density and temperature of two of the principal components expected to be present in the Venusian exosphere, and measure the abundance of electrons in the ionosphere of Venus and in the space between the earth and the spacecraft.

The occultation experiment does not involve any specialized equipment. When the spacecraft appears to move behind the planet, its radio signal passes obliquely through the Venusian atmosphere and is diffracted, and the propagation velocity of the signal is changed. Measurements of these changes to the radio signal can yield significant information about the Venusian atmosphere.

Mariner Venus 1967 spacecraft





Mariner Mars 1969 spacecraft

Mariner Mars 1969

The Mariner Mars 1969 Project will take the next step in the exploration of Mars with two launches in the spring of 1969 for flyby passages of the planet in August. Use of the Atlas/Centaur launch vehicle permits increasing the spacecraft weight to accommodate a large battery of planet-scanning scientific instruments; however, no interplanetary fields and particles instruments will be flown. The primary objective of these flights is to make exploratory investigations of Mars which will set the basis for future experiments, particularly those relevant to the search for life, with a secondary objective of developing the technology needed for succeeding Mars missions.

The 1969 Mars mission involves a number of differences from the 1964 Mariner IV mission, although there is considerable similarity of the basic spacecraft design concepts. The flight time in 1969 is shorter, the injection velocity requirement is greater, the communication distance at encounter is smaller, and a higher rate of data return is expected. Approach to the planet will be much closer, and an equatorial and a south-polar pass are planned for the two flights. Pictures will be taken of the whole planet, starting 48 hours before closest approach.

The scientific payload will include a two-camera television experiment (wide- and narrow-angle), with the picture format having 16 times as many elements as the Mariner IV format. About eight narrow-angle pictures of the whole planet will be obtained in the far-encounter mode, and 25 alternating wide- and narrow-angle pictures during the close flyby. An infrared spectrometer will provide data on atmospheric composition and properties and on surface composition and thermal emission. An ultraviolet spectrometer will obtain data for the identification of specific atmospheric constituents and their concentrations at various altitudes, and an infrared radiometer will chart the variation of surface temperature with location. Two experiments involving radio occultation and celestial mechanics, similar to those performed by Mariner IV, will provide data on the physical properties of the atmosphere and the fundamental parameters of the solar system. A data storage system, employing both analog and digital tape recorders and storing nearly 40 times the information recorded by Mariner IV, will store the planetary scientific data for post-encounter return to earth.

System design, integration, assembly, and testing are to be carried out by the Laboratory, with industrial contractors undertaking the detailed design, fabrication, and testing of the various subsystems.

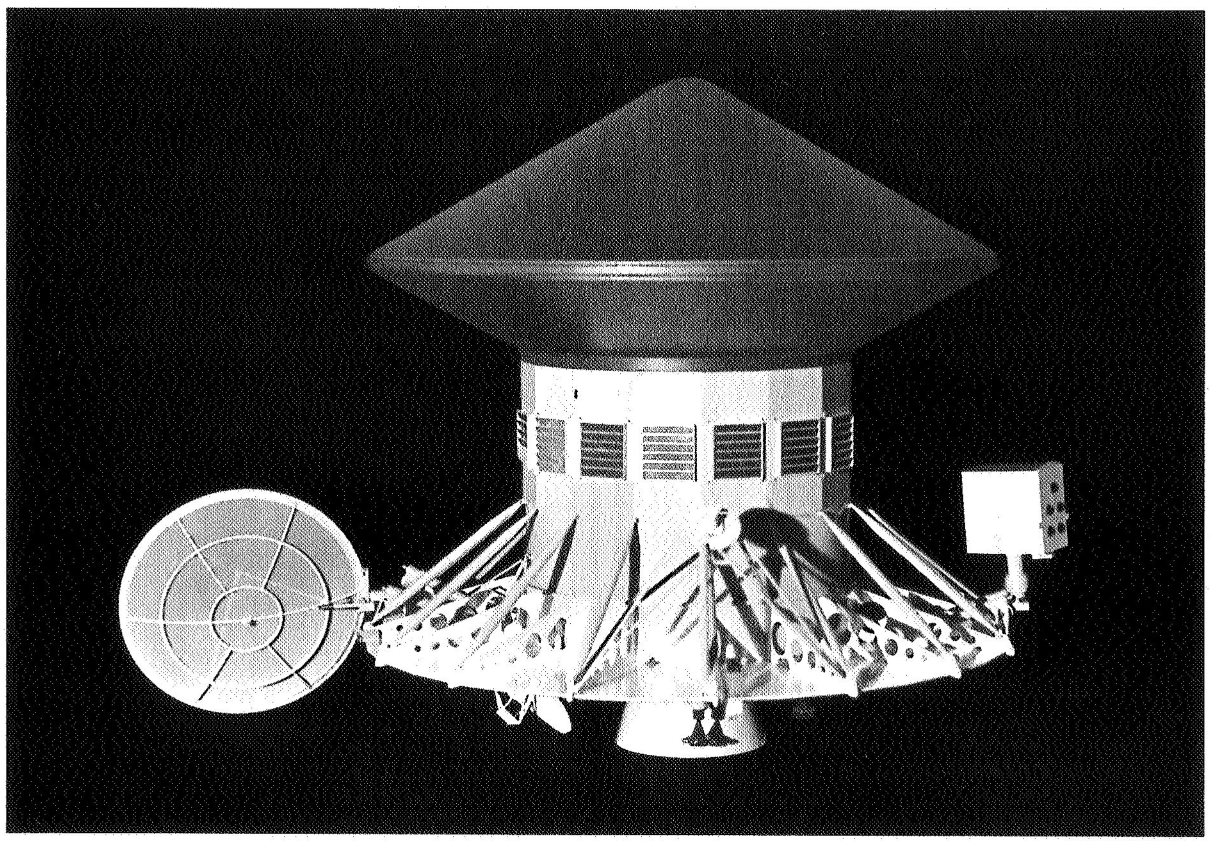
VOYAGER

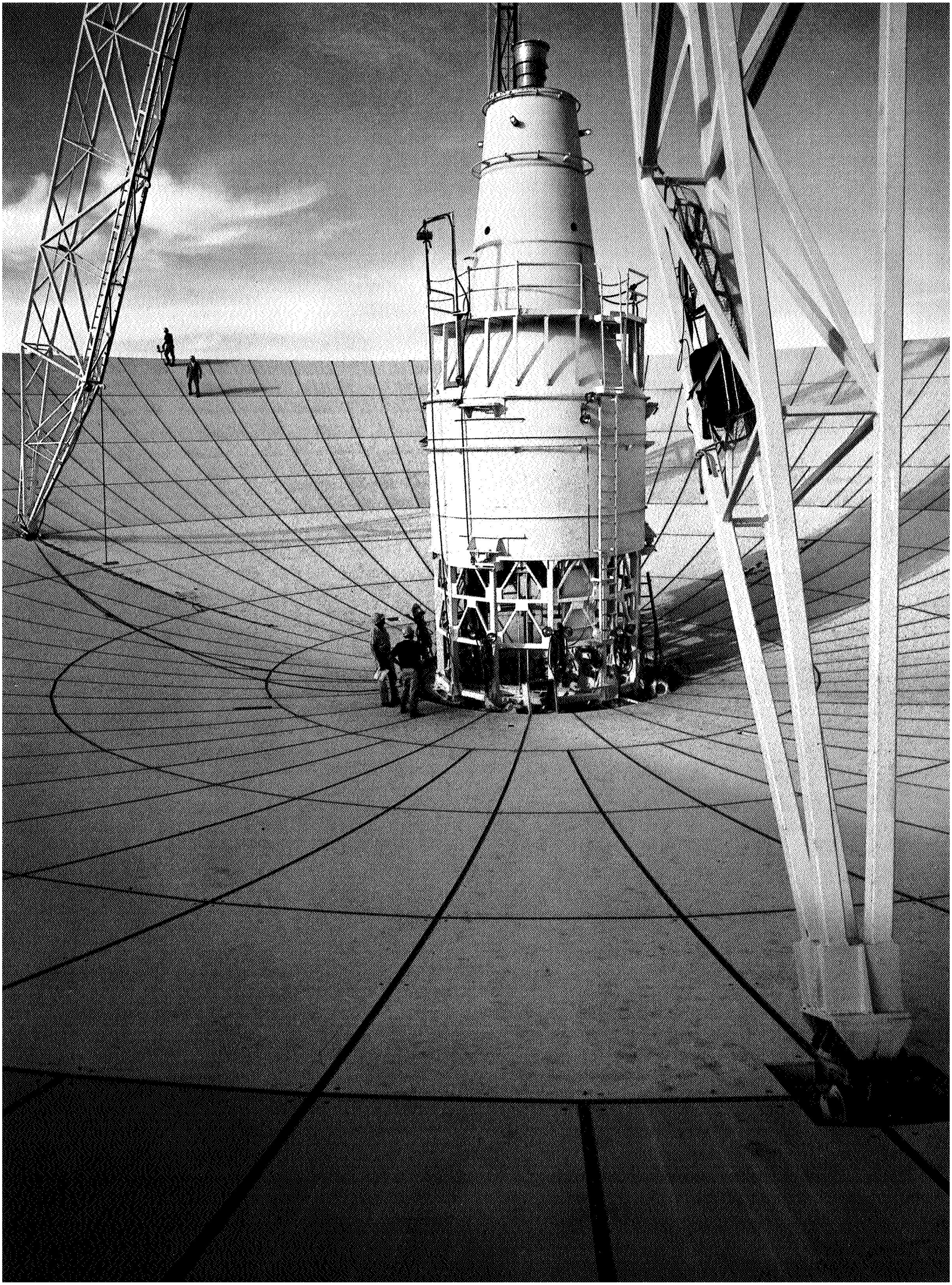
The Voyager Project will carry out scientific investigations of the solar system by instrumented, unmanned spacecraft which will fly by, orbit, and/or land on the planets. Emphasis will be placed on acquisition of scientific information relevant to the origin and evolution of the solar system, the origin, evolution, and nature of life, and the application of this information to an understanding of terrestrial life. The primary objective of the first Voyager missions to Mars in 1973 is to obtain additional information about the existence and nature of extra-terrestrial life, the atmospheric, surface, and body characteristics of the planet, and the planetary environment. A secondary objective is to further the knowledge of the interplanetary medium between earth and Mars by obtaining scientific and engineering measurements while the spacecraft is in transit.

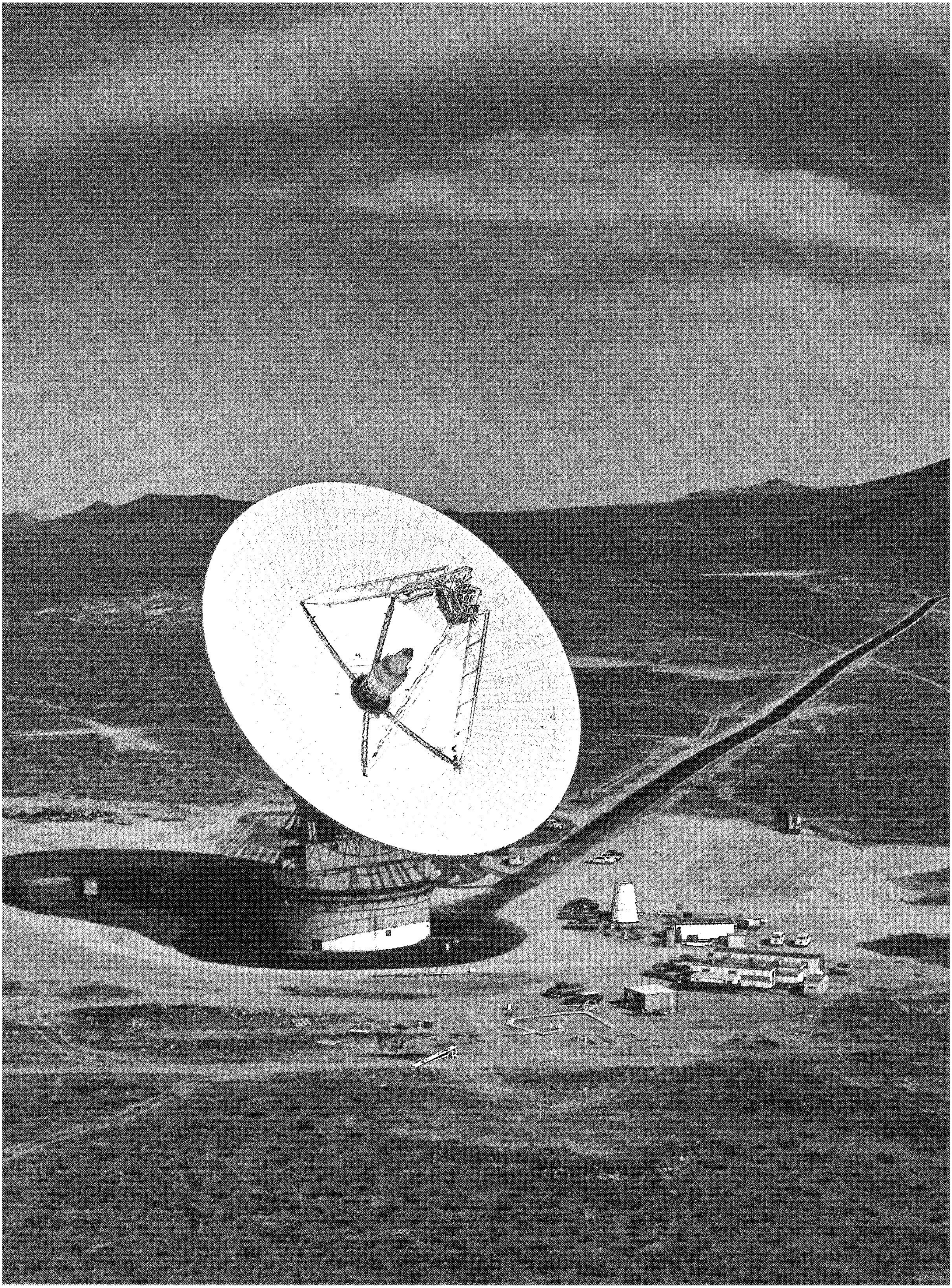
Present planning provides for an integrated series of missions in the 1973, 1975, 1977, and 1979 Mars opportunities. In each mission, two planetary vehicles will be launched by a single Saturn V; each planetary vehicle will include a spacecraft, capsule bus, and surface laboratory system. Planetary quarantine constraints will be applied throughout to avoid possible contamination of Mars during the conduct of life experiments.

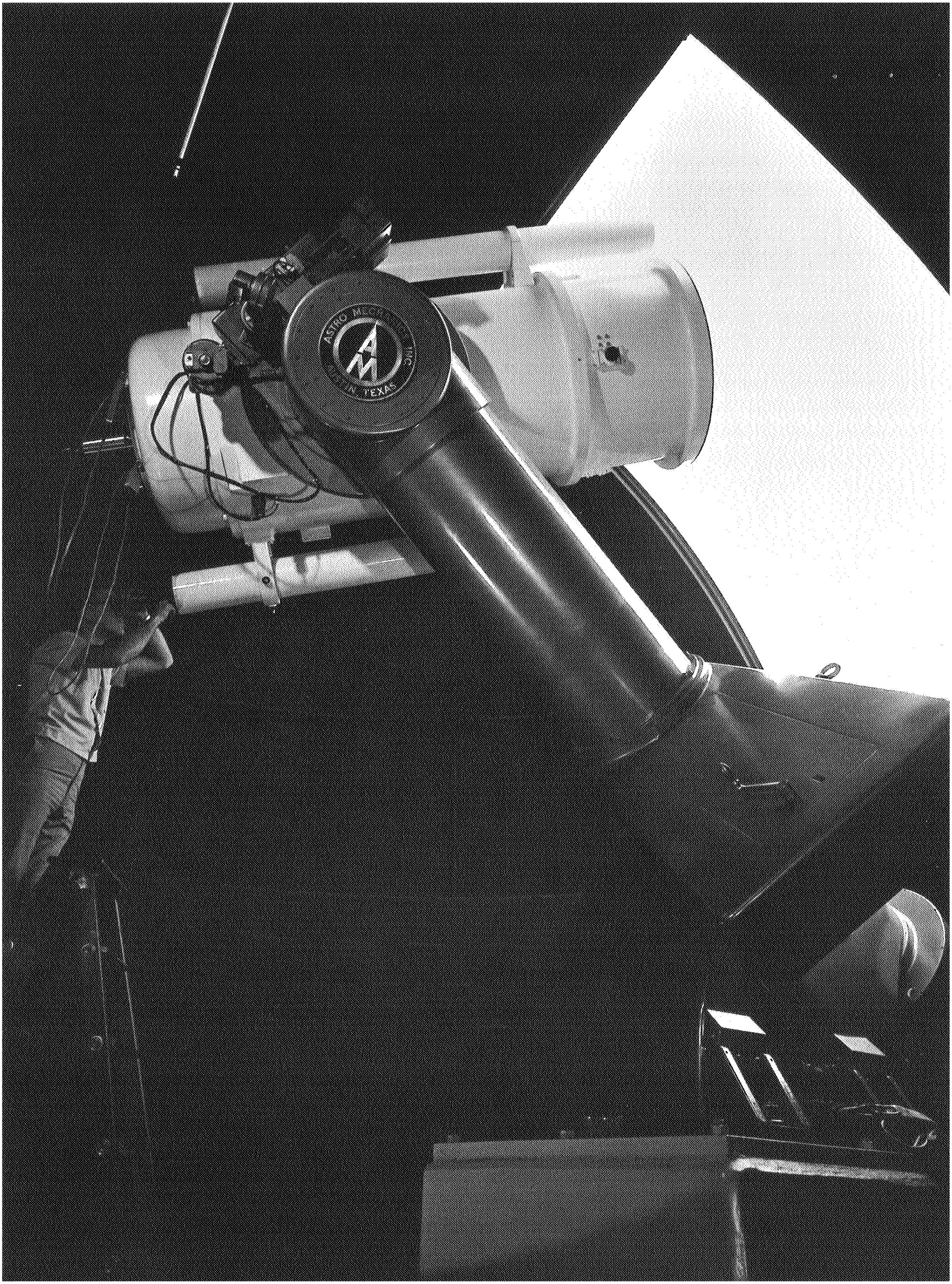
At the conclusion of 1965, Voyager was reprogrammed to a first mission to Mars scheduled for 1973. During the reporting period, Voyager Project management at JPL emphasized development of the management techniques, the advanced technology, and the overall mission concept to be employed on Voyager. A number of options for the latter were examined which culminated, near the end of the year, in a modular concept that could be used over a number of mission opportunities. This mission concept, identified as VPE-14, was based on orbiting the planet before dispatching the entry capsule (because of the thin Martian atmosphere determined by Mariner IV) and using Surveyor techniques to descend to the surface. This approach permits a sizeable scientific laboratory to be placed on the planet surface for making biological measurements and performing other surface operations.

Model of Voyager planetary vehicle









The Deep Space Network

OPERATIONS

During 1966, the Deep Space Network (DSN) successfully provided tracking and data acquisition for Surveyor I, Surveyor II, Lunar Orbiter I, Lunar Orbiter II, Pioneer VI, Pioneer VII, Atlas/Centaur 8, and Atlas/Centaur 9, while at the same time continuing tracking and telemetry coverage of Mariner IV. Because of the intensive activities through the year, most of the stations were often in operation 24 hours a day, 7 days a week.

The operations were unusual as well as numerous. Useful telemetry was obtained from Mariner IV when it was on the far side of the sun. More than a hundred thousand commands were sent to Surveyor I as it accomplished its photographic mission on the lunar surface. After landing on the moon, Surveyor I was used as an extreme distance collimation tower for obtaining antenna patterns for the 210-foot antenna. Lunar Orbiter was used for relaying ranging signals from one DSN station to another, resulting in station-to-station time synchronization from continent to continent to within a few microseconds.

Four new stations were added to the Deep Space Instrumentation Facility (DSIF) during the past 18 months. The construction of the Ascension Island station was completed in early 1966. This station is of a gap-filler type, and uses a 30-foot-diameter antenna for data acquisition during the early part of flights launched from Cape Kennedy. The Robledo station near Madrid, Spain, became operational in mid-1965, and the Cebreros station, near Robledo, was completed at the end of 1966. Both Spanish stations are maintained and operated with the aid and cooperation of the Spanish Instituto Nacional de Técnica Aeroespacial (INTA).

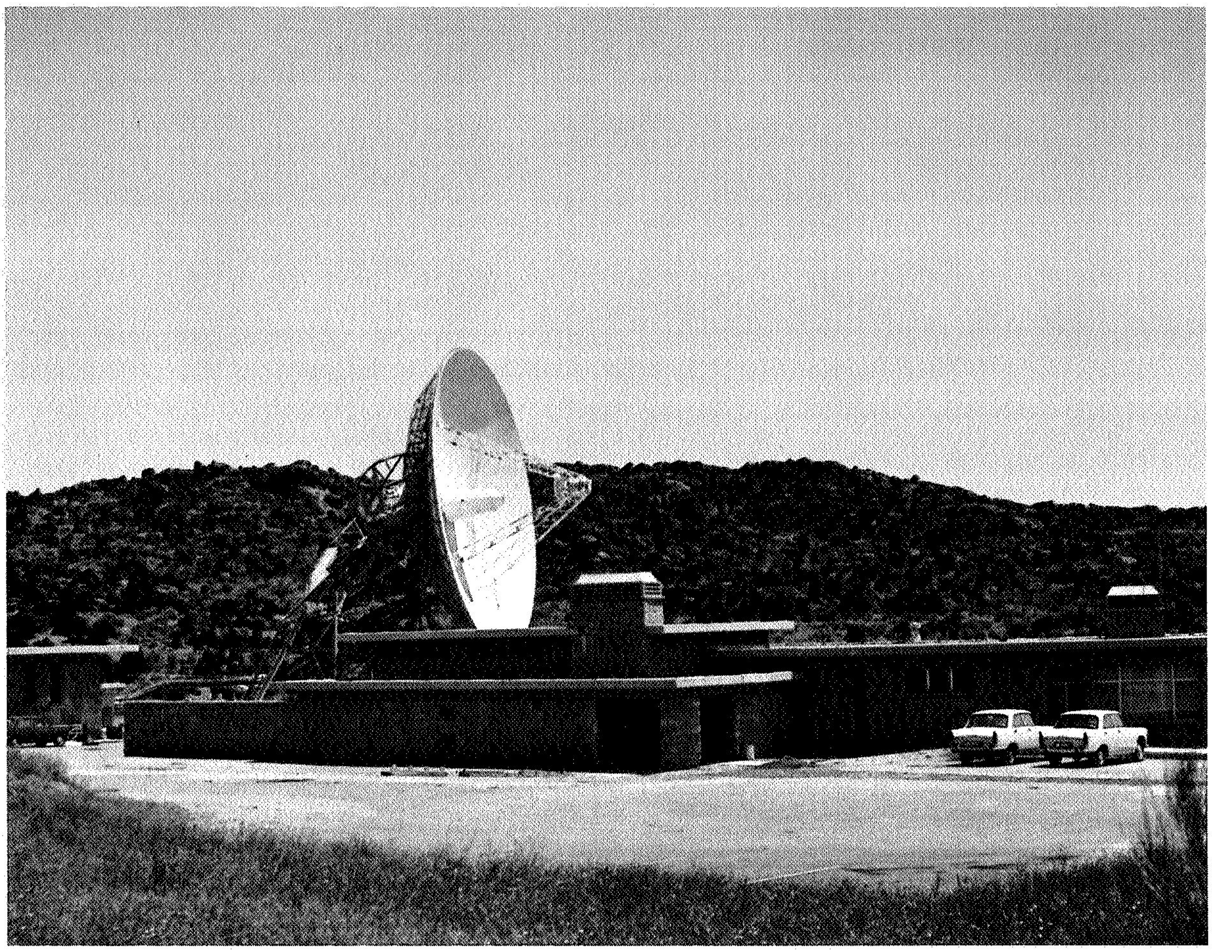
On April 29, 1966, the Goldstone 210-foot antenna was officially dedicated by Chairman George P. Miller of the House of Representatives Science and Astronautics Committee. This antenna is one of the world's largest, most advanced precision tracking systems. The 210-foot antenna system has been supporting tracking missions and gathering telemetry data on deep space vehicles which are beyond the capabilities of the 85-foot diameter antenna at DSN installations. The 210-foot antenna increases the effective range of deep space telemetry about three times over that of the 85-foot antennas; alternately, the larger antenna provides six to ten times as much data at the same spacecraft range. The operating 210-foot installation at Goldstone is the first of a planned three-station network that would include 210-foot diameter antennas in Australia and Spain.

A third major computer string was added to the original two strings in the Space Flight Operations Facility (SFOF). This major equipment addition was made during a period of high flight project support activity without significant interruption of the projects. A fourth computer string is in process of installation. Two additional computers were installed in the SFOF, one as a communications processor, permitting rapid handling of incoming teletype streams of data from the stations, and another to expand the simulation facility. A standby power system was built to minimize the effects of major electrical power outages on flight operations support.

MARINER IV REACQUISITION

A significant accomplishment in spacecraft telecommunications in 1966 was the reacquisition and tracking of Mariner IV at a distance of 210 million miles. After successful completion of the Mars encounter, the spacecraft telemetry transmissions were switched from the high-gain to the low-gain antenna in anticipation of reacquiring telemetry when Mariner again came close to the earth in mid-1967. The signal level at the earth therefore dropped sharply. For the first 7 months after Mars encounter, no earth-based tracking stations were capable of receiving telemetry data from the spacecraft. However, the presence of the very weak signal could still be detected by the Venus station at Goldstone, California, using techniques related to those employed in radio astronomy.

OPPOSITE: *Workmen standing on the primary reflecting surface indicate the scale of the new 210-foot DSN antenna.*



The new DSN Robledo station near Madrid, Spain

Even though intelligible spacecraft-to-earth telemetry could not be obtained, it was still possible to send ground commands to the spacecraft during this period using a 100-kilowatt transmitter at Goldstone. Beginning on October 1, 1965, twelve commands were transmitted to the spacecraft, some at distances greater than 210 million miles, a record for commanding a spacecraft from the earth. It has subsequently been verified that eleven of these twelve commands were properly received.

On May 3, 1966, the new 210-foot-diameter antenna station at Goldstone was activated and acquired the Mariner IV signal in such a way that intelligible telemetry could be produced. The data thus recovered indicated that the spacecraft was still operating and appeared to be in excellent condition. Telemetry has continued to be received from Mariner IV since that date, with the quality increasing as the Mariner once again approaches the earth.

210-FOOT ANTENNA RADIATION PATTERNS USING SURVEYOR SIGNALS

Antenna patterns from large antennas are conventionally measured using radio beacons atop high towers. In order to avoid near-field effects and ground reflections, the distance of the tower from the antenna and the height of the tower must be fairly large. Furthermore, the larger the antenna diameter, the greater the distance and height of the tower. The collimation tower required for a 210-foot antenna would have had to be on the order of 20 miles away and several miles high. Such a tower was, therefore, clearly impractical.

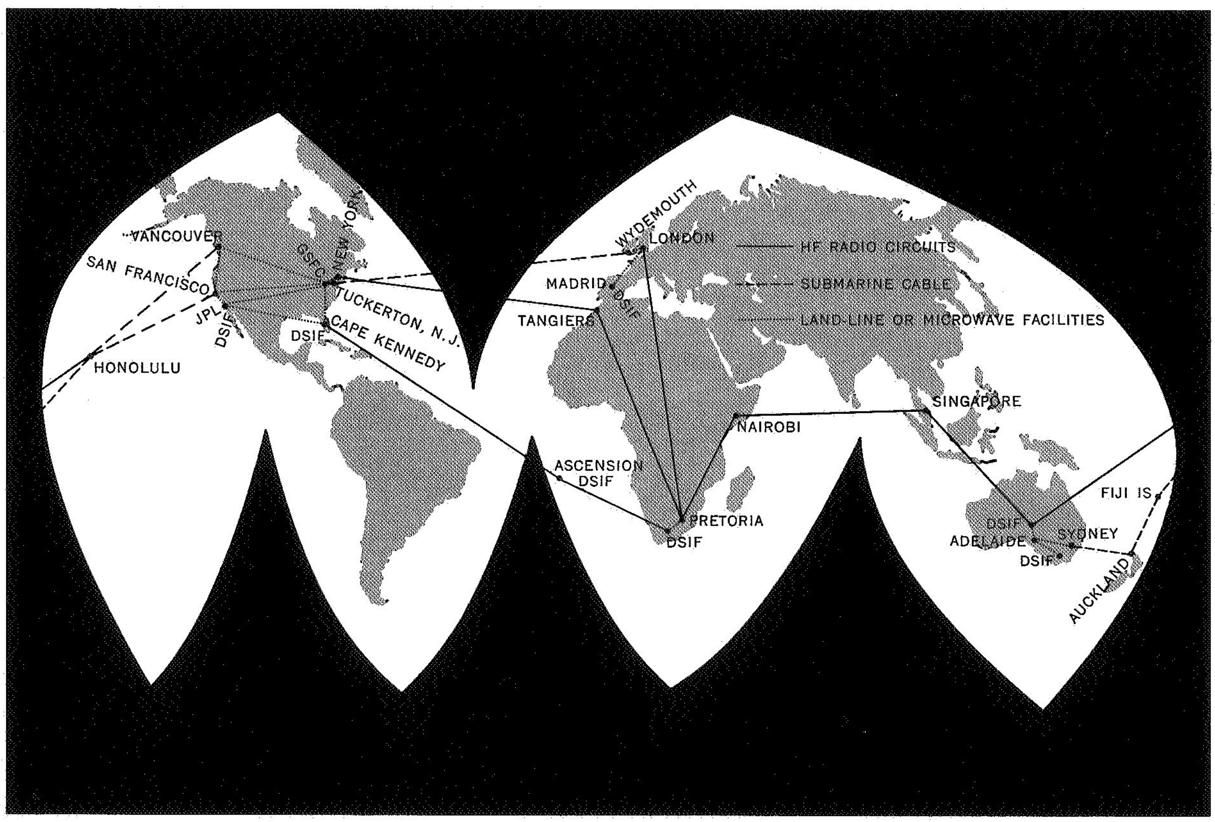
The soft-landed Surveyor I on the moon presented a unique opportunity to obtain antenna patterns because of its distance from the earth of 240,000 miles, the high

elevation angles above the local terrain, and the relatively strong signal level. For the pattern tests, Surveyor transmitted normal telemetry in the low-power mode through its high-gain planar array; the antenna had a listening feed with a traveling-wave maser input. The receiver automatic gain control voltages were digitized, and the patterns were reduced on an IBM 1620 computer. It was thus determined that the 210-foot antenna patterns were well within specifications and in accord with theoretical calculations.

STATION-TO-STATION TIME SYNCHRONIZATION USING LUNAR ORBITER

For the determination of certain kinds of spacecraft orbits such as those around the moon or the planets, it is important that the DSN tracking stations around the world be very accurately synchronized in time. Conventional time synchronization methods can produce synchronization to on the order of a few milliseconds; the requirement for the spacecraft orbit determination is on the order of 10 to 50 microseconds. A technique was evolved using ranging equipment at the DSN sites and the transmission from one station to another by way of the Lunar Orbiter spacecraft in orbit around the moon station to achieve not only synchronization between the stations but the required orbit determination precision as well. Synchronization to an accuracy of 10 microseconds was relatively easily obtained, and it may well be better than a microsecond. The synchronization accuracy was confirmed by air-transporting a very stable atomic clock from one station to another during the flight operations. This technique, and others, have now determined the location of all the DSN stations with respect to each other to an accuracy of a few meters. The ranging technique, sometimes referred to as the pseudo-noise technique, was developed at JPL over the past 10 years. The distance (or range) to the spacecraft from a tracking station can now be measured in less than 1 minute and to a

Facilities of the Deep Space Network are world-wide.



precision of about 50 feet. Using a simple amplifier on the spacecraft, this technique permits range measurements to a distance of more than 800,000 kilometers. With somewhat more elaborate equipment, ranges of hundreds of millions of miles can be measured to a precision of 50 feet.

AN IMPROVED TRAVELING WAVE MASER SYSTEM

A new and improved model of a traveling wave maser operating in a closed-cycle refrigerator has been in operation on the Mars 210-foot antenna for approximately 6500 hours. A particularly useful feature is a low-cost, highly reliable closed-cycle refrigerator using readily available equipments and materials. A fixed Joule-Thompson valve and a gas-filled thermal switch have contributed to a system requiring a minimum of adjustments. A new method was employed to provide cooling for the inner conductor of the signal-input coax. An equivalent noise temperature of around 5°K was thus achieved, significantly increasing the sensitivity and reliability of the station.

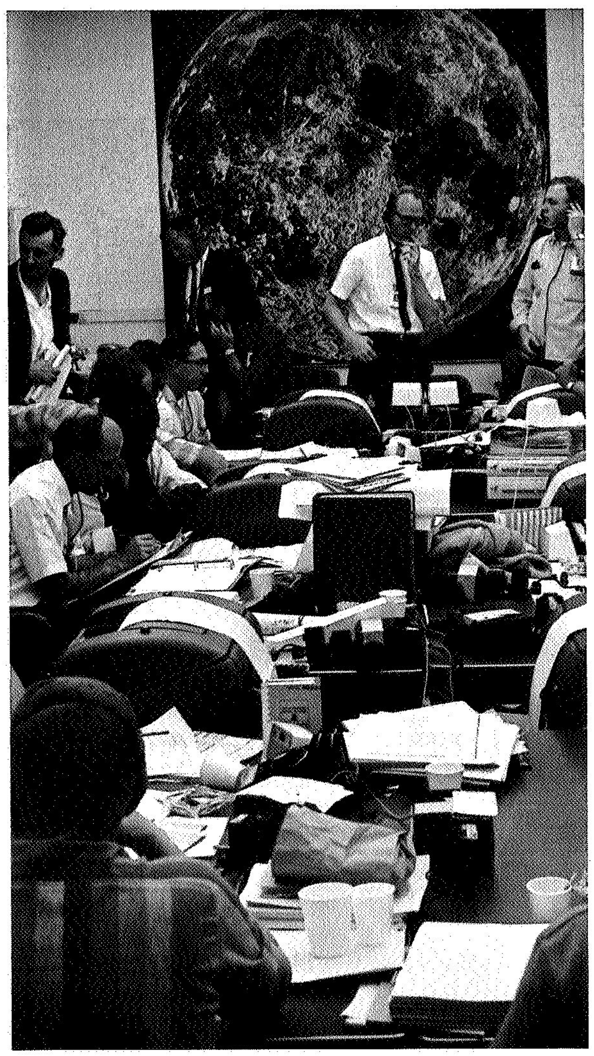
OTHER ADVANCED DEVELOPMENTS

Improvements continued to be made on the 100-kilowatt transmitter at the Goldstone Venus site, with emphasis on the development of diplexing equipment which would allow simultaneous high-power transmitting and low-noise receiving. More precise calibration techniques were devised to measure received signal level and antenna efficiency. A radiometer was developed which, used in conjunction with a standard angle-tracking feed, provides angle pointing and gain calibrations of the antenna systems based on radio star sources. The latter development is especially important for the regular collimation of the 210-foot antenna, for which a collimation tower is impractical.

A special receiver was built for acquiring Mariner IV telemetry at the 210-foot antenna site. The receiver used a 3-cycle loop bandwidth, a high-Q VCO, and a local oscillator whose frequency was controlled on the basis of spacecraft trajectory information. This receiver extended the range by a factor of 2 at which 8-bit-per-second, Mariner IV telemetry could be received by the 210-foot antenna station, placing the entire orbit of Mariner IV within range of the Goldstone facility.

An unanticipated result of tracking Mariner IV as it flew near the sun was a considerable disturbance of the otherwise pure carrier wave of the Mariner IV. The signal passed within ¾ degree of the surface of the sun and thus served to probe the solar corona. Spectrograms of the signal show considerable doppler broadening, which gives some insight into the turbulent nature of the corona and interplanetary scintillation, as well as providing design information for communication systems that must operate through this region.

SFOF activity during the Surveyor I mission



OPPOSITE: *210-foot antenna in the desert at Goldstone, California*

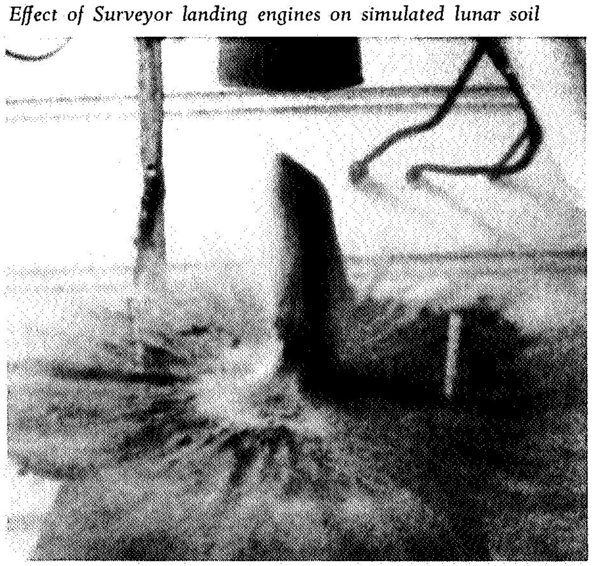
RESEARCH

The Jet Propulsion Laboratory maintains a strong and continuing program in the research areas of fluid physics, electrophysics, materials, and applied mathematics. The purpose of this basic research effort is the accumulation of fundamental knowledge and understanding of physical phenomena. It is anticipated that the new knowledge and understanding now being generated will find application in the solution of future problems in space exploration, many of them as yet unforeseen.

Generation of Dust in Ultrahigh Vacuum

Concern has been expressed about the effects of accumulated lunar debris on spacecraft thermal control surfaces. It was expected that significant particle-to-particle adhesion would occur if a solid sample of material was ground into fine particles under ultrahigh vacuum conditions (10^{-10} torr). Experiments were conducted in an especially designed

Effect of Surveyor landing engines on simulated lunar soil



apparatus which allowed a solid sample to be ground after extended time in vacuum at temperatures of 400–600°F. The most important finding was that little tendency existed for the fine particles to agglomerate. Several types of solid samples were used, including some with nearly 100% of theoretical density. Complete evaluation of the test results has not been made, but it seems possible that the lack of particle adhesion may be due to contamination of the freshly generated surfaces by dissolved or trapped gases which were liberated during the grinding operation.

Electron Flow in Very Thin Oxide Films

Thin film junctions consisting of two metallic layers separated by an oxide layer are of great interest in the area of electronic devices. Oxide films with thicknesses in the range of 10–15 Ångstroms present a problem inasmuch as it is extremely difficult to determine the quality of such thin films. By measuring the tunneling currents in thin film junctions in the superconducting state, and by comparing the results thus obtained with the predictions of Josephson's theory, it was possible to ascertain the quality of these very thin oxide films. Thus far, activities have been limited to studies of lead-oxide-lead junctions. The dielectric constant and the thickness of the oxide film were determined from the Josephson effect data, and the data were used in a study of normal-state tunneling through lead-oxide-lead thin film junctions. The oxide barrier potential and the tunneling path length were determined for a junction with an oxide film approximately 15 Ångstroms thick. The same technique should be applicable to junctions formed from other metals also.

Plasma Velocity Measurement

Experimental work with a giant pulsed laser led to the development of a laser tracer diagnostic technique to measure plasma velocities. Until recently, measurements in plasmas were made utilizing Langmuir probe and

OPPOSITE: *24-inch Cassegrain/Coudé reflector telescope at the Table Mountain Observatory*

accoustic techniques, electrical discharges, and magnetic velocity probes. These methods all lack spatial resolution and generally disturb the plasma that is being observed.

The laser tracer technique is relatively simple to use. A giant pulse laser is discharged, and the laser light is focused at a predetermined point in the plasma flow. In much less time than the dwell time of the plasma in the region being measured, a drop of fully ionized plasma is formed in a volume of the order of a cubic millimeter. The velocity of this plasma drop is measured utilizing a rotating-drum camera. The method is applicable over a wide range of plasma properties, and may be the only technique that can be used at extremely high temperatures, where probe techniques fail because of inadequate cooling.

Solid-State Battery

During investigations of the mechanism of electronic conduction in polymers, it was found that a charge transfer complex consisting of an aromatic hydrocarbon (e.g., perylene), intimately mixed with a halogen (e.g., iodine) and placed between magnesium and carbon electrodes, is capable of delivering useful electrical power. The aromatic hydrocarbon may be replaced by a large variety of organic compounds as well as a number of polymers to yield improved batteries characterized by remarkable simplicity and ease of manufacture. Earlier solid-state batteries offered only very low open-circuit voltages (0.2 to 1.0 volt) and low current densities (100 $\mu A/cm^2$). As a result of the conduction investigations, solid-state batteries may be constructed which have an open-circuit voltage of 2.5 volts and a short-circuit current density of up to 25 mA/cm^2.

The present findings constitute the first case of a practical application of charge transfer complexes which have been under active investigation for the last 50 years. The solid-state batteries described constitute promising power sources for energizing microelectronic circuits for pyrotechnic devices as well as for electromedical applications. Although the energy density of the prototypes thus far studied is below the requirements for space vehicle power, substantial improvement of present power capability and performance may be expected.

Processing of Friable Polymers

Because of their high temperature stability and radiation resistance, p-Polyphenylenes are potentially very useful, but their extreme insolubility in all common solvents prevents fabrication of these polymers by the usual polymer processing techniques. Recently, the technique of isostatic pressing was adapted to the fabrication of these friable insoluble polymers. The success of this procedure depends on the ability of a pressurized liquid to transmit compacting pressure evenly to all sides of a flexible mold enclosed in a pressure vessel. The method offers potential for processing polymeric materials, especially extremely insoluble powders, with unique, desirable, and/or improved mechanical properties. The results obtained depend on the powder, the compacting pressure and pressure application rate, the void content of the powder within the mold, the use of additives (if any), and the dwell time. Advantages realized or expected from this procedure include (1) uniform strength in all directions regardless of size; (2) uniform compaction regardless of outer contour complexity; (3) minimization of voids with concomitant uniform densities and reduction of internal stress concentrations; (4) uniform compaction regardless of length-to-diameter ratio; (5) low tooling cost; and (6) safe processing of hazardous, exotic, or expensive materials with minimum scrap losses.

Guidance and Control

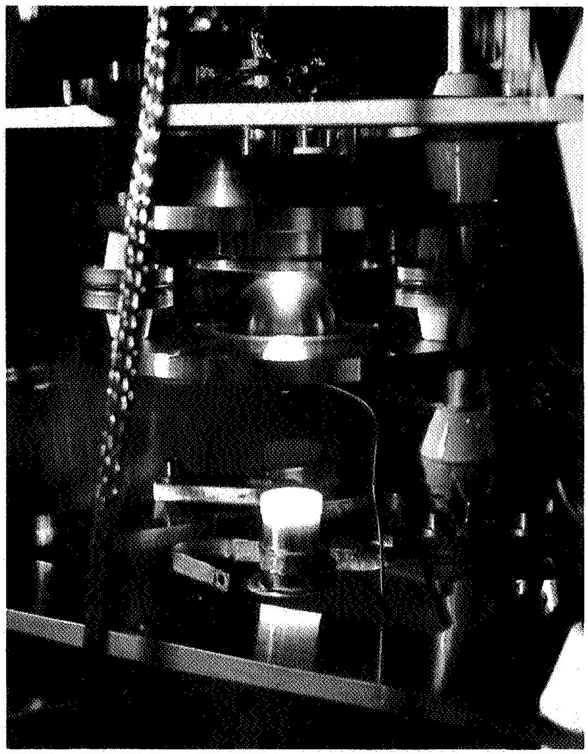
Several solid-state and physical electronics research tasks were performed with the objective of demonstrating the feasibility of applying these physical phenomena to new guidance, control, and power devices:

1. As a first step in demonstrating the feasibility of a space-charge-limited triode, a scheme was devised for incorporating a "gate" or control electrode into a space-charge-limited germanium diode.

2. A new infrared detector, called a "thermactor," was invented that depends on a variation of capacitance with temperature, rather than the usual variation of resistance, as in a thermistor. The thermactor should be more than an order of magnitude more sensitive than a thermistor.

3. Work done on the propagation of high-frequency sound through liquid helium II was used as part of the experimental basis for a new theory of liquid helium II developed in Russia.

4. A new theory was devised to explain charge-carrier transport through a cesium plasma, and work was nearly completed on a test setup to demonstrate the feasibility of using a magnetic field in conjunction with a diode of special geometry to obtain increased output voltage.



Thermionic emitter heated by electron gun

5. Work was started in three new areas of solid-state physics: (1) the use of cadmium sulfide films in support of the development of improved photoconductive light detectors; (2) the possible application of superconducting films in associative computer memories; and (3) the use of manganese-bismuth films in the development of high-density computer memories.

Plasma Physics

The behavior of a neutral line in a plasma was observed experimentally in a double-inverse pinch apparatus. The neutral line is produced at the line of first contact of two cylindrical shock waves; the gas is preionized, and the region behind the hydromagnetic shocks is highly conducting.

This study has wide application; it is particularly pertinent to the understanding of solar flares, which create a serious radiation hazard to manned space flight. The present effort is the first known direct experimental attack on this problem. Results thus far have provided a good accounting of many phenomena observed in solar flares, and suggest a number of new concepts which should make possible considerable extension of present solar flare theory. The magnetic neutral line behavior observed also has direct bearing on particle acceleration processes in the earth's magnetosphere currently thought to be the primary cause of the aurora polaris.

Nuclear Magnetic Resonance

It has been demonstrated that nuclear magnetic resonance techniques would be a feasible way to determine moisture content on lunar and planetary surfaces. A small, low-powered (milliwatt), transistorized, wide-line spectrometer operating on mercury batteries was constructed and tested. By means of this instrument, water contents as low as 0.19% could be detected in rock and soil samples. The effect of large amounts of paramagnetic impurities was tested by measuring amounts of water of hydration in samples of $Fe_2O_3H_2O_3$ and was found to be minimal.

A new, advanced design with improved signal-to-noise ratio and frequency modulation was also constructed. Adequate ruggedization and reduction of weight and power requirements for actual flight instrumentation appear to present no great problems.

Reduction of Turbulent Heat Transfer in Rocket Nozzles

One of the important results of the convective heat transfer investigation being conducted at JPL is the finding that a reduction in turbulent heat transfer can occur when a turbulent boundary layer is accelerated at comparatively low Reynolds numbers. This phenomenon has been found in various configurations of conical rocket nozzles and in convergent rectangular channels, and it is believed that it can occur in accelerating flows in general. The significance of this finding is that the phenomenon can be used to advantage in the design of rocket thrust chambers.

Low-Thrust Trajectories

A considerable advance was made in the calculation of the trajectories of interplanetary vehicles propelled by low-thrust propulsion systems, such as ion engines. Previously, the initial and final position and velocity of the vehicle in the heliocentric frame were simply assumed to be those of the departure and arrival planets, respectively. For vehicles of very low thrust (5×10^{-5} earth g and less), this assumption is seriously in error.

The new technique (called the asymptotic velocity intercept method), developed for digital computer calculation, takes into account the initial and final velocities of the low-thrust vehicle relative to departure and arrival planets. This technique is now being applied to planetary missions, making possible the optimization of total missions, including injection vehicle, low-thrust vehicle, and retro-vehicle. Results have shown large increases in the scientific payloads that can be carried to other planets by low-thrust vehicles.

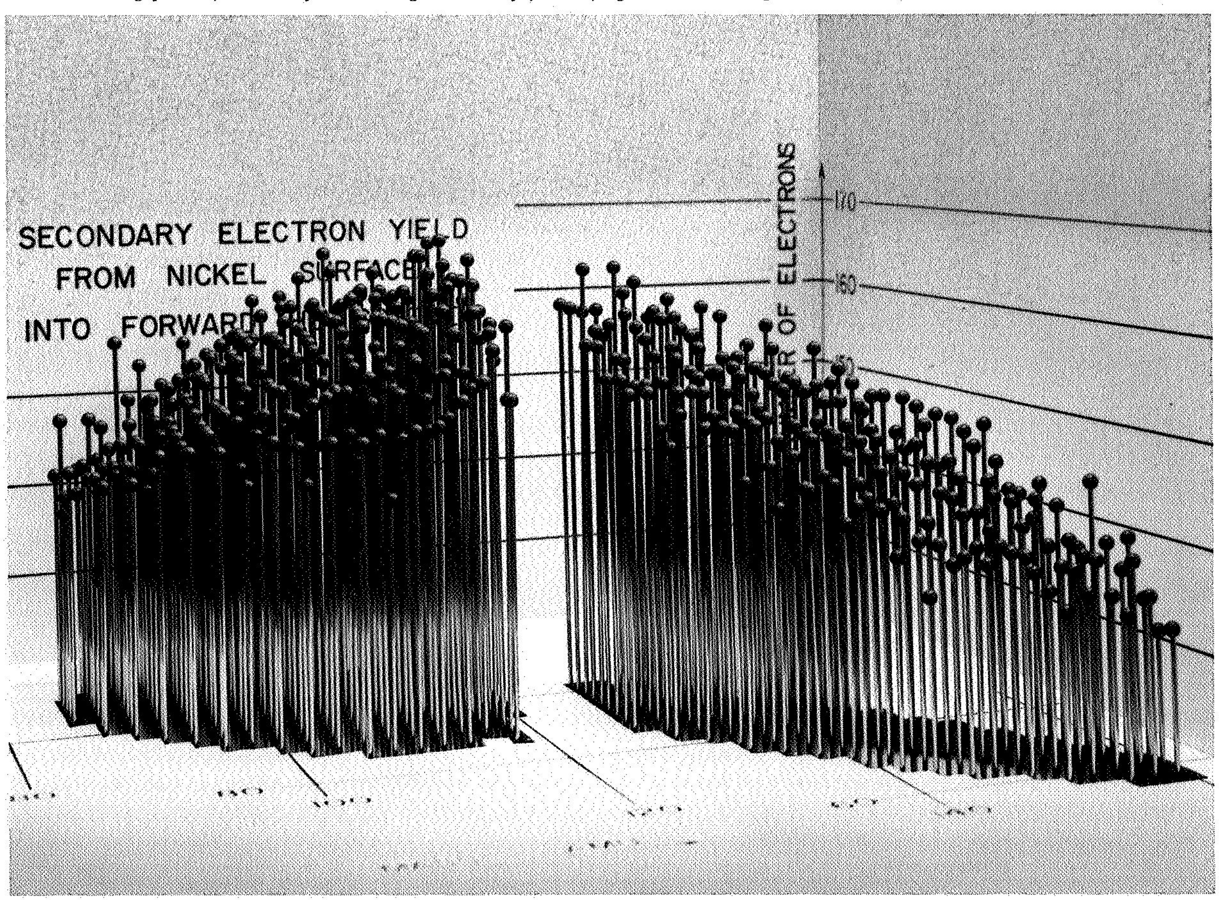
Secondary Electron Yields From Fission Fragments

The yields of secondary electrons ejected from thin foils by the passage of fission fragments through the foils were measured as a function of fragment energy and mass for different foil materials. The fragments originate in a spontaneous fissioning Cf^{252} source mounted on a very thin foil. They are detected and their energies measured by means of solid-state detectors on either side of the source. The secondary electrons are ejected from a foil of selected material (Al, Ni, Ag, or Au) placed between the source and one of the detectors. Number and energy spectra of the ejected electrons are then determined with an electrostatic spectrometer.

The experiment, which is part of a continuing program in fission physics and the interaction of heavy ions with matter, is fully automated, with the data-acquisition system recording results on magnetic tape for direct input to a digital computer. Computer programs have been written and utilized for correcting detector calibration drift, recognizing and rejecting errors in the data, computing the kinematics of each fission event from the detector responses, and generating an output of electron yields versus fragment mass and energy.

A time-of-flight system with 1-nanosecond resolution has been constructed for a continuation of this experiment, in which the secondary electron yield will be correlated with specific energy loss of the fragments in the foil.

Model showing yield of secondary electrons generated by fission fragments traversing a thin nickel foil



PHYSICAL SPACE SCIENCE

The space science program includes both ground-based planetary observations and laboratory development of techniques for future spacecraft experiments. The ground-based operations include observations made using two optical telescopes at the JPL-NASA Table Mountain facility and telescopes at a number of other observatories, radio-telescope observations of planetary phenomena, and radar reflection experiments with the near planets. Techniques are being developed for determining planetary surface and atmospheric properties from orbiters, flyby vehicles, probes, and landers. All space science development tests are specifically undertaken in the expectation of later application either on JPL missions or as flight science experiments on non-JPL vehicles.

Hydrogen Compounds in the Martian Atmosphere

During the 1965 opposition of Mars, near-infrared spectra were obtained at the Observatoire d'Haute-Provence, France, with a Connes-type Michelson interferometer. In collaboration with the French experimental group, these spectra were analyzed at JPL. The resolution obtained of about 1 cm^{-1} from 5700 to 6950 cm^{-1} (1.44 to 1.75 μ) and 4 cm^{-1} from 4050 to 4550 cm^{-1} (2.20 to 2.47 μ) is far better than has ever been achieved before, and resulted in the discovery of unexpected absorption bands that extend through most of the spectrum. These bands are apparently caused by the presence of gaseous compounds containing hydrogen in the Martian atmosphere; they probably include substituted methanes—perhaps methane itself.

This finding may have important implications for the possibility and nature of life on Mars, since hydrogen compounds are generally considered necessary to both the origin and the sustenance of planetary life. Lack of evidence for the presence of atmospheric hydrogen prior to this discovery had been a significant argument against the possibility of life on Mars.

Geological Sampling

Among the most crucial implements for unmanned planetary exploration will be devices that obtain and deliver suitable samples of planetary material to the geological instruments for examination. Since samples of bedrock are desired, and they must be reduced to small particulate form of controlled size for examination, attention has focused on drilling and grinding devices. Laboratory models were developed of grinders, rotary impact drills, abrading sieve cones, rock crushers, and particle conveyors.

Microwave Surface Properties

The behavior of the radar echo from known areas of the earth's surface is being studied, as a function of altitude, for altitudes up to 150 kilometers. The results will ultimately provide a powerful tool for gaining information about the terrain and surface materials of planetary surfaces from orbiting spacecraft.

L-band radar systems were flown on the NASA Convair 990 research aircraft and on an Aerobee 150 sounding rocket over the Tularosa Basin area of New Mexico. Echoes were obtained from altitudes of 5, 10, 80, and 166 kilometers. Transmitted pulses were measured by means of instruments buried at known depths down to 6 feet. Samples of materials from the target area are being analyzed for water content, void ratio, mineral content, grain-size distribution, and electrical characteristics. Correlation of the experimental results with theoretical expectations is now under way.

Radar echo data from Surveyor I were also examined and found to be consistent with those predicted from earth-based radar measurements. The dependence of radar cross-section on terrain roughness has also made it possible to use these data, in conjunction with radio tracking information and Surveyor and Lunar Orbiter photographs, to establish the location of the Surveyor I landing site.

Optical Astronomy

A new 24-inch Cassegrain/Coudé reflector telescope was installed at the NASA-JPL Table Mountain facility in a building equipped with a rising observation floor, a Coudé observing room, and a dark room. A Connes-type high-resolution interferometric spectrometer is being installed in the Coudé room. Formal observations began in May 1966 at Cassegrain focus with a photoelectric photometer.

A new dome was installed on the Table Mountain facility housing the 16-inch telescope in August 1966. This telescope was utilized during the past 18 months in visual patrol of the lunar crater Aristarchus, seeking small "red spots." In addition, a fairly regular photographic patrol of Venus was carried out in anticipation of the 1967 Mariner flight to Venus. Extensive observations were made of the Comet Ikeya-Seki during October and November 1965.

Radio Astronomy

Radar observations were made of Venus from early November 1965 to the middle of March 1966, with conjunction occurring January 26, 1966. Features similar to those observed in 1962 and 1964, which may be mountain ranges, were again seen; a comparison of their motions over the three successive conjunctions suggests that Venus' sidereal period is remarkably close to 243.16 days retrograde. With this period, Venus would present the same face toward the earth at every conjunction.

Observations of Venus made by the DSN during the close approach of January 1966 revealed the same topographic prominences which were discovered during the conjunction of 1964. Thus, it is established that relatively permanent features are fixed to the surface and rotate with the planet. These features have the ability to depolarize microwaves; hence, they are rough to the scale of a wavelength (12½ centimeters). They may well be mountain ranges, although large fields of boulders would also depolarize microwaves.

Venus' period of rotation deduced from these prominences is 242.6 $\pm$0.6 days, retrograde. At this peculiar rate, an observer on Venus would see exactly five solar days between conjunctions with earth. Thus, Venus' rotation involves twin anomalies: a retrograde direction and at least near-synchronism with the earth.

Radar astronomy experiments during the year included extensive X-band lunar measurements, S-band open-loop ranging and total-spectrum experiments on Venus, and total-spectrum experiments on Jupiter.

Spark-Chamber Experiments

A spark chamber, suitable for the study of high-energy protons and alpha-particles in both planetary and interplanetary space, was developed. It consists of four gaps containing two plates each, a plate being made up of 5-mil wires strung 16 to the inch on an insulating frame; adjacent plates are strung in mutually orthogonal directions. Each wire passes through a magnetic core which is flipped by the spark current, making it possible

Balloon carrying spark chamber to measure energy spectrum and angular distribution of cosmic rays at high altitudes

to examine the state of the core system of each plate electronically to determine the particle path. Planar plastic scintillators on each outside face of the spark gaps trigger the spark-chamber high voltage, and are also used to obtain particle energy information from pulse height analysis.

Successful balloon flights were conducted with the spark chamber in Palestine, Texas, and in Fort Churchill, Canada, at altitudes of 125,000 and 127,000 feet, respectively, utilizing 5,000,000-cubic-foot balloons. The first was capable of a vertical look angle only; the second included a motor-driven gear system to provide omnidirectional coverage of the sky. A large amount of data was obtained on the energy spectrum and angular distribution of protons above 50 and alpha-particles above 200 million electron volts in energy.

BIOSCIENCE

The bioscience program is relatively young but is destined to expand as the Voyager Program focuses increasing emphasis on the search for life on Mars. At present, the program can be subdivided into two categories: exobiology supporting research and the Automated Biological Laboratory (ABL).

Exobiology

This effort is designed to provide, with the collaboration of other NASA centers, the technological base for the life detection and characterization experimental hardware. It includes activity in scientific experiment formulation, studies of the growth and photosynthetic characteristics of microorganisms, application of powerful laboratory instrumentation such as a combined gas chromatograph–mass spectrometer to life-related compound identification, and studies of the effects of Mars-like environments on terrestrial microbiota.

Of these, the latter is the most noteworthy. During the past 18 months, soil samples were obtained from the Eastern Sahara and the Chilean Atacama deserts for the purpose of determining their microbial content. These areas were chosen for their arid, and perhaps Mars-like, climatic conditions. To date, no soil tested, no matter how dry, has been found without viable microbiota.

A trip to the Antarctic was recently undertaken in order to investigate still another climatic variant and its effects on living organisms. The findings should be particularly relevant to the question of frozen subsurface water and its relationship to life support.

Automated Biological Laboratory

The ABL program, officially initiated in March 1966, consists of a study made to define the specific scientific objectives and strategy for the biological exploration of Mars, and a number of related technology development activities.

The study has made considerable progress in establishing a strategy. A formalized hypothesis testing methodology has been chosen, and efforts are now under way to translate a selected set of hypotheses into experiments and then into spacecraft instrumentation.

The ABL technology development efforts have included studies or hardware developments in each of the four ABL subsystems: (1) sample acquisition and transport, (2) sample processing (including both mechanical and wet chemical), (3) instruments and detectors, and (4) control and data handling. The first of these subsystems has received the most emphasis to date, since its function is a prerequisite to the others.

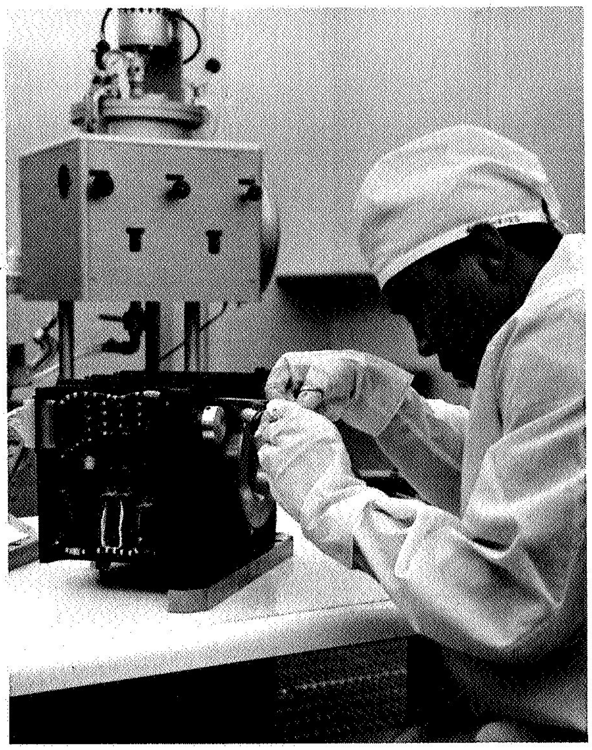
SPACE SCIENCE AND TECHNOLOGY FLIGHT EXPERIMENTS

An activity of considerable importance is the development and construction of scientific experiments to be flown on vehicles other than JPL spacecraft. These have included high-altitude balloons, Aerobee rockets, NASA aircraft, and earth orbiters. Lunar orbiters and manned lunar landing flights are also scheduled to carry JPL experiments. The scientific investigator teams involved in these experiments frequently include faculty and staff members from universities and personnel of various NASA Centers.

OGO-E Solar Wind Spectrometers

The fifth in the series of Orbiting Geophysical Observatory satellites (OGO-E), to be launched in 1968, will carry two JPL instruments to investigate the detailed properties of the plasma out to about 120,000 miles from the earth. The instruments will be identical, but one will be mounted on a solar panel, and oriented toward the sun, and the other will be on the body of the spacecraft, pointed outward from the earth, so that a wide range of directions can be covered.

The plasma spectrometers will measure the properties of the undisturbed solar wind when the observatory is



Electronic assembly of OGO-E plasma spectrometer

near apogee on the sunward side of the earth, and the properties of the plasma in the magnetosheath, the magnetosphere, and the magnetospheric tail at other times.

The spectrometers are more complex than any flown before. Each contains two independent measuring instruments: a curved-plate electrostatic analyzer, which measures the differential flux and energy spectrum of protons and electrons in a relatively narrow acceptance cone, and an ac-modulated Faraday cup probe that measures the total proton flux within a wide acceptance cone and determines the mean direction of plasma flow within this cone. The two sensors are thus complementary.

The distinctive features of the OGO-E experiment are its capability of making measurements with high resolution in energy and high time resolution at the same time. The total flux probe can measure the flux and direction of the plasma seven times per second at the highest OGO telemetry rate (64,000 bits/sec). The electrostatic analyzer can obtain a complete 32-point energy spectrum approximately every 10 seconds. This capability is provided by a programmer computer which continually keeps track of the position of the peak in the plasma energy spectrum and selects that set of 32 energy windows (from the 128 available) which fits the observed spectrum at any one time. Thus, a complete energy range from 2 to 16,000 electron volts can be covered, but only the most interesting portion of that range is measured.

ALSEP Solar Wind Spectrometer

When the first manned Apollo lunar landing is accomplished, the astronauts will set up a group of experiments on the moon's surface which will function automatically and return data to the earth for one year thereafter. This experimental operation, known as the Apollo Lunar Surface Experiments Program (ALSEP), includes an ac-modulated multiple Faraday cup solar wind spectrometer being developed at JPL.

This instrument will measure the energy spectrum and direction of the electrons and protons flowing from the sun which strike the lunar surface. It contains seven gridded Faraday cup detectors oriented to give coverage of the entire sky. The upper and lower bounds of the ac modulation, which is applied to one grid of each detector, determines the energy of electrons or protons that can enter and be detected. Fourteen energy windows ranging from about 100 to 10,000 electron volts will be used for protons and seven windows from about 1 to 100 electron volts for electrons. The direction of the incoming solar wind at any time is determined from the relative amounts of current flow in the seven detectors.

Biosatellite Fluorometry Experiment

A study of the metabolic balance of a primate during prolonged weightlessness will be one of the principal experiments of the 30-day Biosatellite D flight. The Biosatellite project is under the direction of the Ames Research Center; the primate metabolic balance experiment is a joint endeavor involving staff members at UC Berkeley, UCLA, and JPL.

Instrumentation is being designed and constructed at JPL for automatic sampling and analysis of urine at 6-hour intervals during the entire flight under zero gravity conditions. Analysis by fluorometric means is used to determine the concentrations of calcium, creatine, and creatinine; pH will also be measured.

The techniques developed for operating miniature-scale wet-chemical processes repetitively and automatically will lend themselves to future planetary exploration programs. An exciting possibility for future earth-based use of some of these techniques exists in the development of automated hospital laboratory systems.

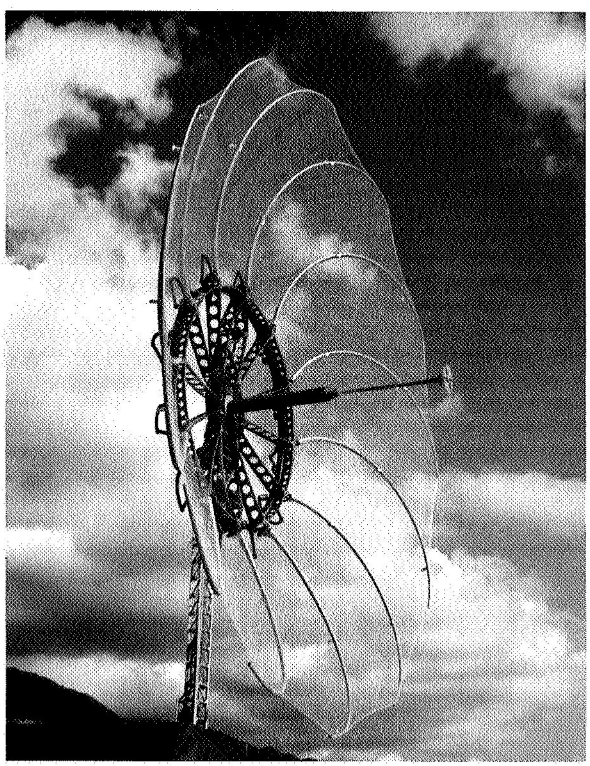
Lunar Orbiter Selenodesy Experiment

The first two of the series of Lunar Orbiters have been successfully placed in orbit around the moon. Enormous quantities of data have already been collected from these two orbiters, and some preliminary results calculated. Improved digital computer programs are simultaneously being evolved for obtaining final results.

The analysis of the radio tracking data will lead to more accurate values for the lunar oblateness and eccentricity of the lunar equator, the coefficients of the higher harmonics of the lunar gravitational field, and a new, independent determination of the mass of the moon. These constants pertaining to the mass and mass distribution of the moon will be of considerable interest with respect to questions of the origin of the moon and the earth-moon system, the internal composition of the moon, fundamental astronomical constants, and related problems.

The gravitational constants will further be useful in planning for later lunar orbital missions and in verifying the trajectories for manned Apollo missions. In addition, the process of determining gravitational constants also yields the most precise orbit possible, which will aid in locating the terrain that was photographed.

Large unfurlable spacecraft communications antenna



Temperature Sounding Experiment

A satellite-borne infrared radiometer is currently under development designed to obtain atmospheric temperature information on a world-wide scale for use in meteorological studies of circulation and weather prediction. This multidetector radiometer measures the radiation emitted from the ground and the CO_2 in the atmosphere at a wavelength near 4.3 microns. The data are used to derive atmospheric temperatures at several altitudes between sea level and 150,000 feet.

The multidetector radiometer is now under test and will be flown on a high-altitude balloon in January 1967. The purpose of this flight is to verify the validity of the experimental approach.

A logical follow-on to an earth satellite experiment with this instrument is the remote sensing of the Martian atmospheric temperature from a fly-by or orbiter mission.

ELECTRONICS

Electronics research contributes to the technology of telecommunications, including both spacecraft and ground subsystems, guidance and attitude control, and control and data handling. In addition, it is a part of the spacecraft systems discipline and its primary elements, electronic components reliability and electronics packaging.

Telecommunications

The next-generation ground-based telecommunications radio subsystems—antenna, low-noise (maser) amplifier, and tracking receiver—have achieved a state of performance approaching the optimum. For this reason, telecommunications R/AD has concentrated on the spacecraft.

In the area of higher-power radio-frequency power amplifiers (transmitters), two major developments were made: an electrostatically focused klystron with a variable power output between 20 and 100 watts, and a high-efficiency 100-watt traveling-wave tube.

In addition to higher-power transmitters, future programs such as Voyager will require larger-aperture spacecraft antennas. Because of volumetric packaging limitations under the shroud, large apertures can only be achieved by erecting, or "unfurling," the dish. A 9-foot-diameter paraboloid with a gain of 32.5 decibels, which is only 4 feet in diameter when stowed, was developed in response to this requirement.

Guidance and Attitude Control

Emphasis in this area has been on the utilization and exploitation of advanced guidance and control components in developmental systems for future planetary missions.

SEAN, an acronym for a Strapdown Electrostatic Aerospace Navigation system, is a joint NASA/USAF undertaking. Its goals are to develop and establish the feasibility of a three-axis inertial navigation system based upon electrically suspended gyros. The primary advantage offered by these gyros is the absence of metal-on-metal bearings and the attendant friction and unreliability. This system could find application in such apparently diverse vehicles as high-performance military aircraft and Voyager Mars orbiters.

The second major systems effort undertaken during this reporting period is the development of an optical approach guidance system to be flown as an experimental "passenger" on the Mariner Mars 1969 spacecraft. Approach guidance permits the spacecraft to determine its position relative to the target planet by on-board measurements in the planet direction with reference to the celestial attitude control references (the sun and Canopus). These measurements are independent from, and therefore complement, the earth-based radio tracking data. The system consists of an image dissector, optical gimbals, and servos for continuous tracking of the planet. For Mariner, the data computations will be done on earth, but future missions might employ an on-board computer.

Other efforts of note include studies of remote operations of a roving vehicle, development of advanced computer-aided optical systems design techniques, studies of guidance radars for soft-landing Mars missions, and analysis of continuous low-thrust (ion engine, for example) orbit-determination techniques.

Control and Data Handling

The control and data-handling effort has been characterized by a greater application of integrated circuits and magnetic devices to spacecraft subsystem development, increasingly computer-like approaches to complex spacecraft control functions, and more sophisticated use of large general-purpose computers for post-flight scientific-imaging data processing.

The spacecraft subsystem which best exemplifies the former two trends is the Mariner Mars 1969 central computer and sequencer. The R/AD program developed the technology base for this digital subsystem, which is to be fabricated primarily from digital integrated circuit elements and which is, in fact, a first-generation spacecraft computer. It has a total of sixteen instructions, can add and subtract, and is fully reprogrammable by ground-based command.

Work has begun on a self-testing and repair (STAR) computer designed to achieve the requisite deep-space mission reliability through a combination of self-testing logic and hardware redundancy at the circuit and subsystem levels.

An area which has received considerable emphasis is that of on-board mass data storage — specifically, tape recorders. Currently defined short-term storage needs fall in the 10^7 to 10^8 bit range, while long-term needs approach 10^9 to 10^{10} bits or more. At the present time, tape recorders are the only known means of providing storage capacity of this magnitude.

The development of an engineering model 10^7 bit tape recorder utilizing peripheral tape drive has recently been completed. This machine will provide the technology base for 10^8 bit and larger capacity recorders.

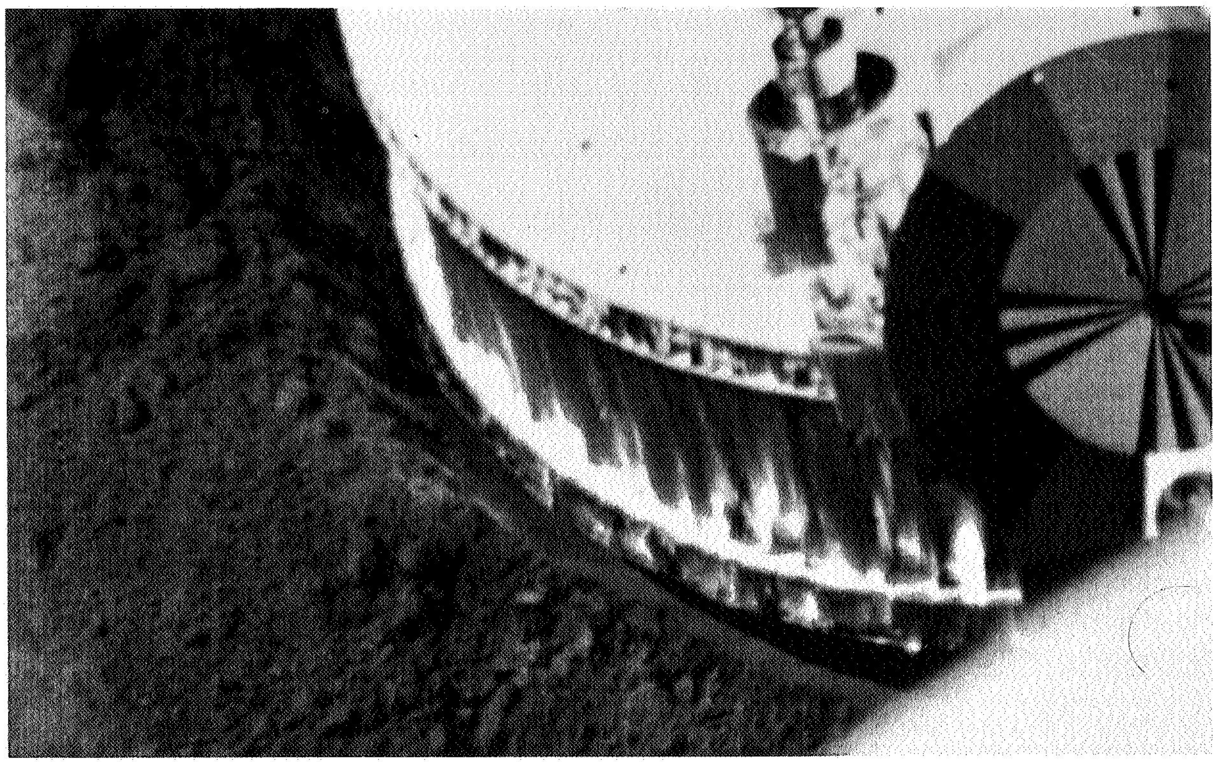
A development which received considerable public attention is the post-flight computer enhancement of the Mariner IV and Surveyor I pictures. The use of the digital computer makes it possible to recover information which could not otherwise be detected. The technique is now being refined for Mariner 69 and Voyager application.

SPACECRAFT AND CAPSULE AERO-THERMO-MECHANICAL ENGINEERING

Work done in structural analysis, structural materials, thermal analysis and control, entry dynamics, heat transfer, and the development of specific, advanced elements of simulation equipment has as a common goal providing a suitable environment in which the hardware can function throughout a mission. In order to establish confidence prior to launch that the spacecraft can survive the environment of space, the conditions to which it will be exposed in flight must be duplicated on the ground and the various spacecraft systems tested under these conditions.

Measurements of Solar Thermal Radiation and Spectral Distribution

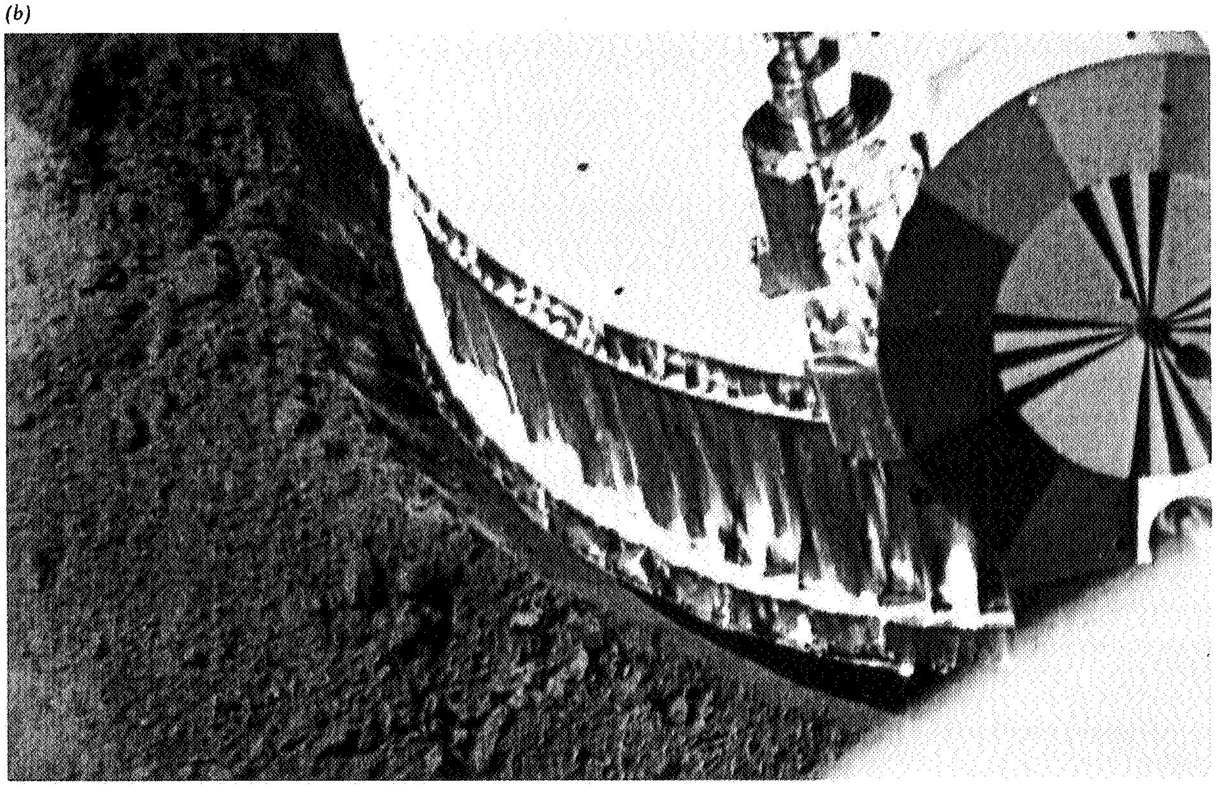
A determination of the solar intensity and spectral distribution in space is of concern in spacecraft thermal control. The values currently being used were obtained



(a)

Surveyor I photograph of spacecraft footpad resting in lunar soil; (a) unprocessed, (b) computer-enhanced

(b)



from ground measurements extrapolated through the ozone layer into space. Two such extrapolations have been recognized as standards, but even they differ by as much as 50% in some spectral regions.

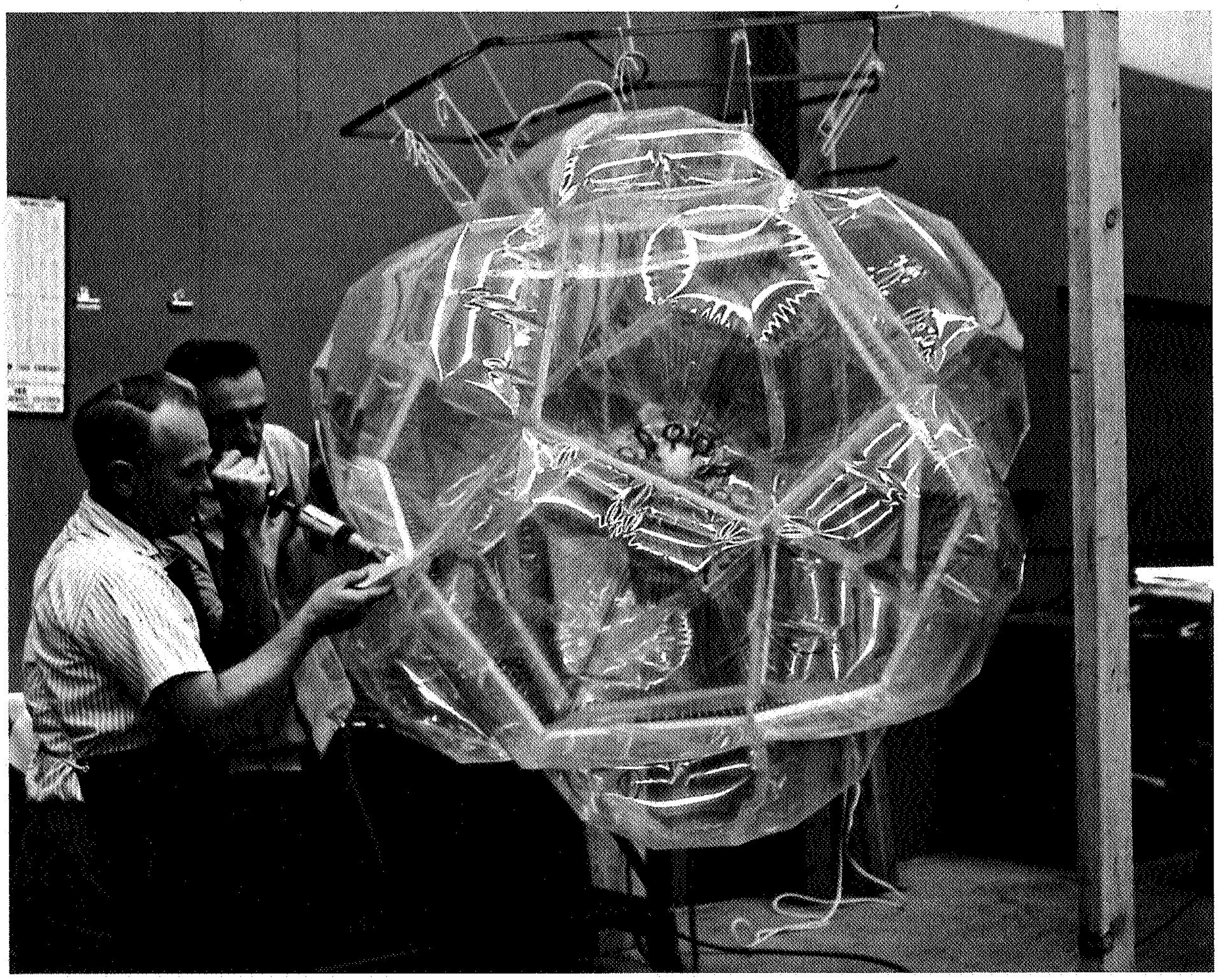
Two devices are now available which will obtain the required measurements directly in space. One is a cavity radiometer designed for the measurement of total thermal radiation; experience to date indicates that it provides a highly accurate absolute standard. The radiometer is now being modified for incorporation as a flight experiment on the 1969 Mariner Mars spacecraft, where it will provide total solar radiation readings over an extended period.

The second device, the solar spectrum measuring experiment, will measure spectral distribution as well as total intensity. This device contains twelve fast-response thermopiles covered with narrow bandpass filters and lenses to provide the spectral information. The experiment has been flown aboard a research aircraft at altitudes up to 45,000 feet and has had one flight on the X-15 research airplane to altitudes above the ozone layer. Additional X-15 flights are scheduled, during which it is expected that the solar spectrum in space will finally be determined.

Impact Absorption

One method of helping to ensure survival of instrument payloads landed on planetary surfaces is to surround the payload with an impact-absorbing structure. A unique technique which has been tested is to suspend the payload inside an air bag, with the bag and the flexible suspension absorbing the impact. The device tested used a mylar "balloon" made of pentagonal segments, with the seams where the segments are joined providing the cable suspension points. This limiter was successfully tested at impact velocities of 175 feet per second.

Pentagonal segments of impact-absorbing balloon being joined at cable-suspension joints



Computer Studies of Shell-Type Structures

The initial version of a computer program for study of the static and dynamic properties of shell-type structures has been completed. This program, Structural Analysis and Matrix Interpretive System (SAMIS), includes the capabilities of (1) generating representation of structures composed of bar, beam, plate, and shell elements in any combination, including mass, stiffness, pressure (thermal induced and inertial loading), and stress matrixes; (2) developing manipulative matrixes by use of any of 14 subprograms to affect solutions; and (3) solving matrix problems of 500th order or less.

MOLSINK

In an effort to simulate the vacuum conditions of space, the MOLSINK (Molecular sink) concept and facility are being developed. The facility consists of a vacuum chamber within a vacuum chamber; the inner chamber is cryogenically pumped at liquid helium temperatures, the outer chamber at liquid nitrogen temperatures. The inner surface of the inner spherical chamber is composed of a series of helium-cooled, wedge-shaped fins to increase the surface area and pumping capacity.

Obtaining vacuum measurements in terms of the proportion of molecules leaving a test item that ultimately return to it required a parallel effort in instrumentation; to this end, a cryogenically cooled quartz crystal microbalance was developed. It consists essentially of a thin quartz crystal whose frequency is precisely known. As particles are deposited on the sensitive crystal surface, the frequency changes, and the change can be related directly to the number of particles deposited.

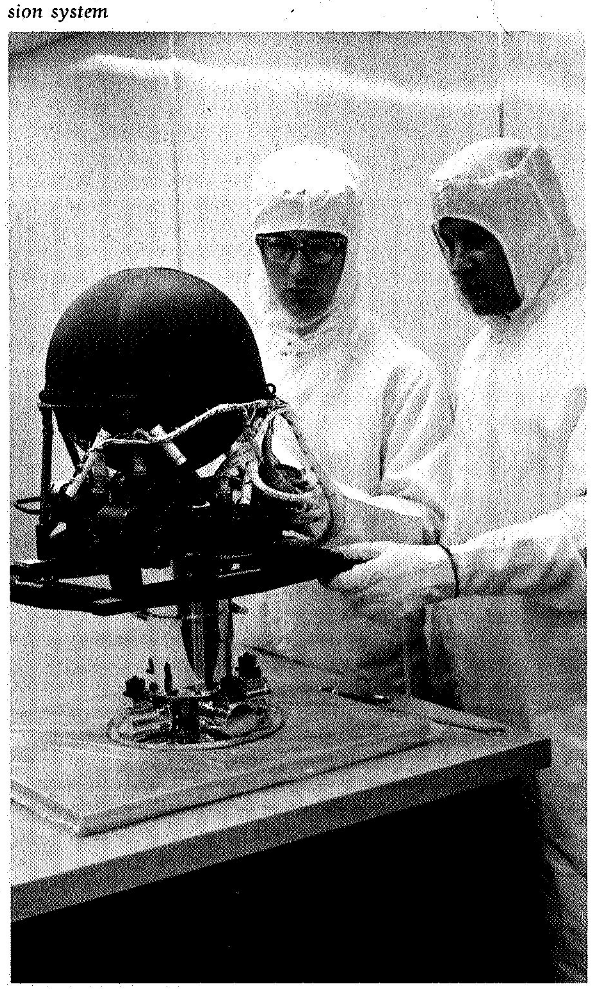
CHEMICAL PROPULSION

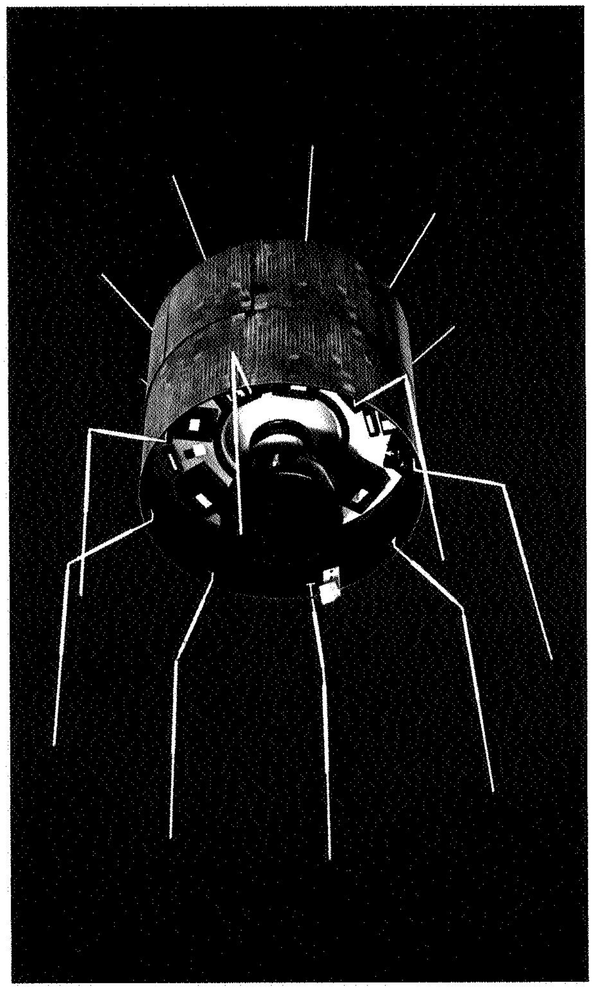
Of particular interest in the field of liquid propulsion technology is the investigation of the phenomenon of resonant combustion in liquid rocket engines, with its steep-fronted, high-amplitude pressure disturbances associated with destructive oscillatory modes. A rotating, detonation-like wave has been postulated, and analytical and experimental evidence to date bears out this concept. It was observed for the first time that the direction of rotation of the fully developed disturbance could be controlled by the circumferential orientation of the initiating bomb.

"State-of-the-art" in liquid technology is exemplified by the midcourse propulsion system to be used on the Mariner Venus spacecraft in 1967. It is an extremely precise, 50-pound-thrust unit using monopropellant-hydrazine, and is typical of the motors used so successfully on previous Ranger and Mariner missions. The use of a monopropellant-hydrazine-generated gas supply is being investigated for application as a more efficient attitude control system on future spacecraft.

One of the more promising higher-energy propellant combinations under consideration is the oxygen difluoride (OF_2) and diborane (B_2H_6) system, offering potential payload increases of 25 to 30%. In addition, both components can be maintained as liquids relatively easily in the space environment. High combustion temperatures, toxicity, and corrosiveness present operational problems currently under investigation.

Technicians assembling Mariner Venus 1967 midcourse propulsion system





Applications Technology Satellite showing JPL-developed apogee motor

JPL has completed the design and fabrication of the solid-propellant apogee motor for the Applications Technology Satellites – a series of satellites to be used for experiments in communications, navigation, and meteorology. The motor is similar in design to the Syncom/Comsat type but much larger, loading 750 pounds of propellant, and has a titanium case.

In order to evolve and substantiate a theory of viscoelastic behavior that will permit the prediction of the response of a solid propellant to a generalized stress-time-temperature field, an active study of the rheological properties of propellants continues. One facet of this effort is focused on the rheology of filled systems, and in particular, slurries. A semi-empirical relation between viscosity and the packing density of the particles in the slurry was extended to relate viscosity and particle size, with an adjustable parameter being a "stickiness factor," or measure of the particle surface energy, which can be obtained independently. Consequently, it is now possible to get rheological behavior of slurries from particle surface energy measurement or, conversely, to obtain surface energy values from rheological measurements. The techniques and theories developed have been applied with preliminary success to the study of blood, which is in effect a slurry of red cells in plasma.

The initial phase of an experimental investigation into the applicability of a pintle-nozzle system for thrust vector control has been completed with encouraging results. Cold-flow tests at supply pressures up to 600 psia incorporated a pivoting pintle extending downstream into the throat of a typical rocket nozzle, with pressure measurements being made at several radial locations and various axial stations in the nozzle. Side forces obtained from the pressure measurements were sufficient to provide a means of thrust vector control.

SPACE POWER AND ELECTRIC PROPULSION

In the vast majority of unmanned space exploration missions to date, the sun has been used as the primary source of energy for spacecraft power. However, for future missions requiring much larger amounts of power or flown at significantly greater distances from the sun, a nuclear reactor will probably be the chief energy source. One of a variety of possible systems for converting the nuclear energy into spacecraft electric power is the liquid metal magnetohydrodynamic (MHD) system under development. Such a system will ultimately use cesium vapor to accelerate 2000°F liquid lithium; the components will then be separated and the lithium decelerated in an MHD generator, producing ac power. Component tests were made initially with a cold liquid metal (NaK) and nitrogen system. A high-temperature lithium erosion loop fabricated of a columbium-1% zirconium alloy was used for materials compatibility testing. A prototype MHD generator was built and tested with NaK, yielding several hundred watts of power within expected efficiencies. Although its overall efficiency is

expected to be lower than that of some competing systems, the MHD system possesses one distinct advantage in that it has no moving parts. For long-duration missions in particular, this could account for a significant increase in reliability.

In order to study the dynamics of a turbo-alternator, alkali-metal, Rankine-cycle, power-conversion system, a two-loop 2000°F lithium-boiling potassium prototype was completed and operated continuously for more than 10 hours at full power.

An additional aspect of the evolution of space power is the development of a heat-sterilizable battery. The element most sensitive to heat sterilization within the battery was found to be the separator, and recent efforts were focused on developing a suitable separator material. From a large number of materials originally tested, a cross-linked polyethylene grafted with acrylic acid was selected for further development and appears to hold promise as a sterilizable separator material.

Extensive studies have been made on the applicability of electric propulsion to space missions as an alternative to increasingly larger chemical boosters. These studies were initially predicated on the use of a flight reactor; however, recent developments in photovoltaics have made it appear feasible to use large solar-cell arrays as the primary power source for electric propulsion.

A program is under way to determine the practicability of large solar-cell arrays. The problems of constructing such an array, packaging it within the confines of the launch-vehicle aerodynamic shroud, and unfolding it in space appear largely mechanical in nature.

During the past year, complete ion propulsion systems were assembled and tested to prove their feasibility for space propulsion. Such a system includes the ion thrustors, propellant tanks and feed system, and the power conditioning and controls.

ADVANCED STUDIES

With increasing emphasis on first-generation Jupiter missions, an intensive study was made of an advanced planetary probe concept to meet the scientific objective of measuring fields and particles in the vicinity of Jupiter. Several spacecraft and mission design concepts were studied for a 12-pound payload consisting of a magnetometer, a Geiger counter with solid-state detectors and ionization chambers, and capacitive film and microphone impact detectors with pulse-height analyzers. Transit times on the order of 500 days were selected as optimum. Resulting spacecraft designs varied from 710 to 830 pounds gross weight, depending on the design approach.

Since the completion of the Jupiter studies in June 1966, the study team has been investigating a combined Venus/Mercury mission for the 1973 launch opportunity. This study makes the first application of the gravity-assist concept, in which a spacecraft injected on a path to a near planet can, under certain conditions, receive sufficient boost from the planet's (e.g., Venus) gravity during its flyby encounter phase to direct it toward the next planet (e.g., Mercury). Trajectory calculations have shown that during certain launch opportunities, not only can sufficient energy be added to the spacecraft by this means, but typically, the transit time to the second planet is shorter (sometimes significantly so) than for the direct, higher-energy path.

The current Venus/Mercury study is nearing completion. Results to date indicate that an Atlas/Centaur vehicle is capable of launching a spacecraft which contains a 200-pound Venus atmospheric-entry probe, as well as significant flyby payloads for both Venus and Mercury. The capsule could contain an aerometeorometer, a mass spectrometer, a visual or ultraviolet photometer, an impactometer, and a three-axis accelerometer. The bus could carry 190 pounds of experiments, including a high- and low-resolution television system, a microwave experiment, an ultraviolet spectroscope, a magnetometer, a solar plasma detector, a trapped-radiation detector, a micrometeoroid experiment, a particle flux/ion chamber, a cosmic ray and solar charged-particle detector, a low-energy proton telescope, and a fast neutron and gamma-ray detector. In addition, the mission appears capable of performing RF occultation experiments at Venus and, under certain conditions, at Mercury also, and a relativity experiment. At encounter for each planet, the system is capable of gathering and storing for later playback 2×10^8 bits of data.

During May 1966, the Future Projects staff was increased in order to perform advanced lunar mission studies. A technique was developed for matching candidate mission concepts against various scientific objectives in order to determine minimum-cost programs under various ground rules. Application of this technique will assist NASA in their long-range planning of lunar exploration.

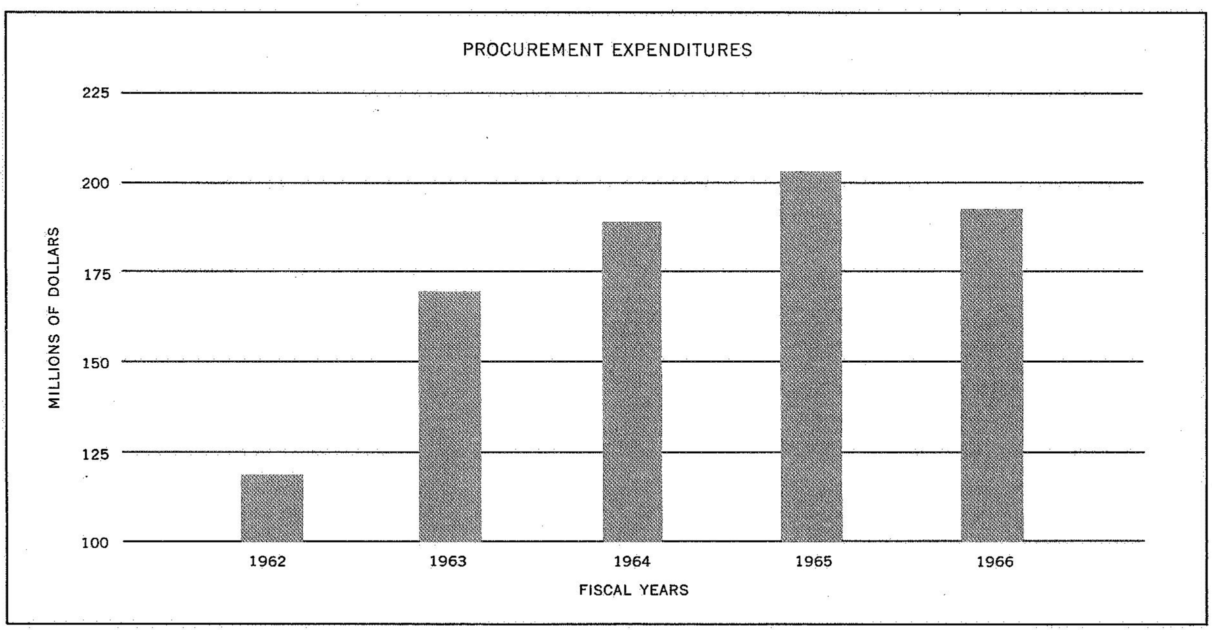
FINANCIAL MANAGEMENT AND PROCUREMENT

Continued emphasis was placed on the use of incentive contracts by the Procurement Division. Two significant examples are the conversion of the Surveyor contract with Hughes Aircraft Company from a cost-plus-fixed-fee type to a combination cost-plus-incentive-award type, and the contract for maintenance and operation of the Goldstone Deep Space Communications Complex with Bendix Corporation, which was written as a cost-plus-award-fee type.

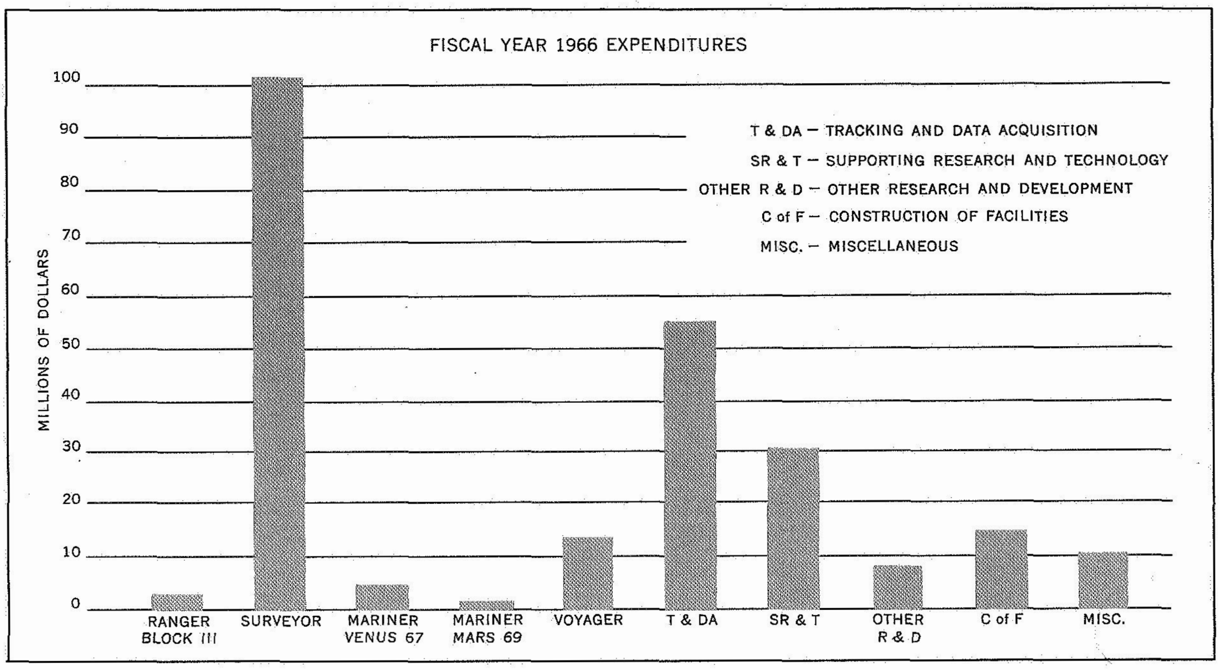
A time cost reporting system is being implemented, which will provide quarterly forecasting of project costs, including updated cost-to-complete information based on data derived from the Technical Managers, the Project Offices, and Financial Management Reports. The Business Systems Section installed an IBM 360 computer to provide business management information more rapidly and at lower cost than the computer equipment used previously.

The Automatic Data-Processing Requirements Office was established to provide a central source of information and control of the automatic data processing equipment and services of the Laboratory in both technical and business applications.

The FY '66 cost reduction goal was 6.5 million dollars. At the close of the fiscal year, the Laboratory reported 8.1 million dollars of validated cost reductions. The FY '67 cost reduction goal is 7 million dollars, and present indications are that it will be attained. A highlight of the Cost Reduction Program was a series of posters displayed at strategic locations throughout the Laboratory. These posters consisted of photographs of familiar persons or objects with suitable captions and proved to be a highly successful means of keeping the program in front of the employees.



OPPOSITE: *Assembly of 23-foot-diameter spherical collimating mirror—the largest in the world—for the 25-foot space simulator*

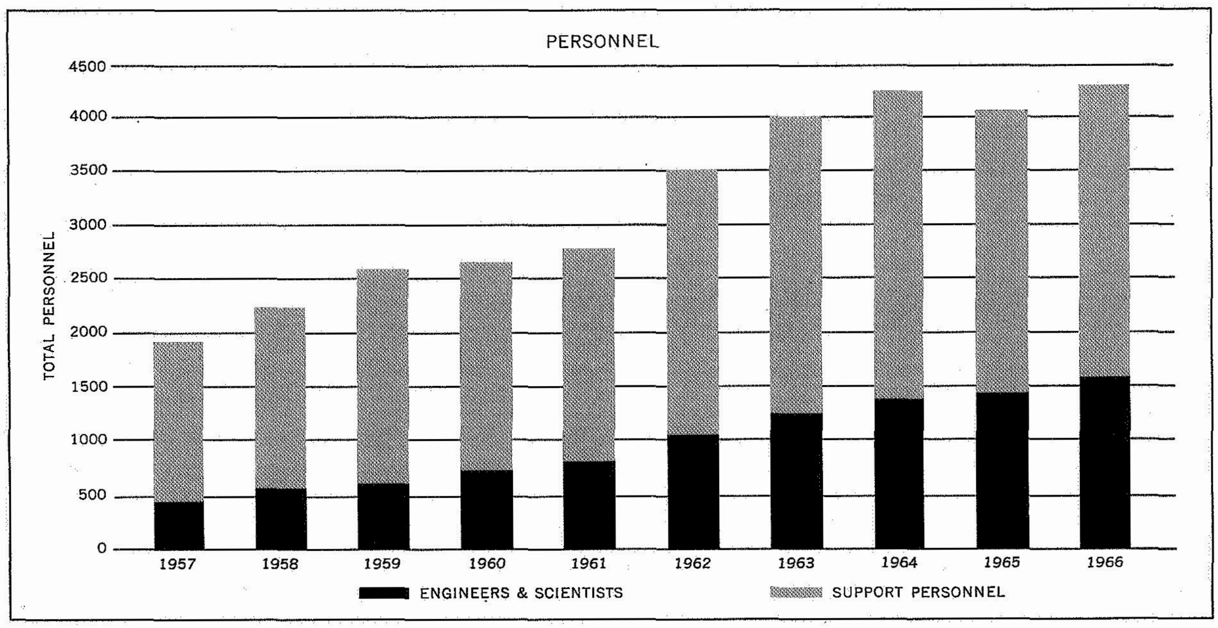


PERSONNEL

With the increase in manpower ceiling from 4000 to 4400, the reduction-in-force trend of 1965 was reversed, and an intensive recruiting effort was initiated. Employee development activities were continued at an accelerated rate.

Changes were effected in employee benefits. The annuity plan was broadened to provide a variable option, and a change was made in the health insurance plan for people over 65 to correlate it with Medicare.

A University Office was established in July 1965 to coordinate JPL's relationship with universities. A new Resident Research Associates Program for the Laboratory



was established under the aegis of the National Academy of Sciences and the new National Academy of Engineering, designed primarily for university faculty, especially in the field of engineering. In addition, assistance was rendered UCLA and USC in their Space Technology Summer Institutes, and similar support was provided the UCLA Summer Institute in Space Biology.

A NASA-Western University Conference was held at JPL in November 1965, featuring the activities of the Jet Propulsion Laboratory, Ames Research Center, and the Flight Research Center. Its purpose was to present the current technical programs of the National Aeronautics and Space Administration of interest to universities and colleges and to describe the various mechanisms through which faculty members can participate in these programs.

Major activity of the Office of Public Educational Services continued in support of both the Laboratory's efforts in general public education and certain NASA programs directed toward teacher-student audiences. Educational material was supplied from JPL sources and from NASA's Division of Educational Programs to assist Los Angeles County school libraries to update and upgrade space-related data, and teachers and students in elementary and secondary schools, as well as colleges and universities were furnished material relative to specific study or research tasks.

Other entities similarly supported in their educational efforts were: the NASA-Western Support Office in Santa Monica, the Caltech Public Relations Office, the NASA Headquarters Division of Special Activities, and numerous public and private museums, planetariums, professional societies, and amateur astronomical and rocketry groups.

PATENTS AND NEW TECHNOLOGY

The Office of Patents and New Technology received 215 reports of items of new technology, of which 170 were formally reported to NASA. From these reports, NASA authorized the preparation of 53 U.S. patent applications.

In the area of new technology, the Office of Patents and New Technology assisted in several technical surveys and other special programs and projects for NASA's Office of Technology Utilization, and replied to 846 requests from industry and laymen for additional information relating to publicized items of new technology.

FACILITIES

Facilities activities during the year included the revision and updating of the Master Plan for JPL for the 10-year period ending December 1975. A Master Landscaping Plan was also developed, with construction and planting beginning about the end of December 1966.

The Space Sciences Laboratory, a 97,000 square-foot, nine-story structure housing physics and chemistry laboratories, offices, and a machine shop was ready for occupancy late in 1965. The Materiel Services Building, a combination warehouse and office structure covering 70,000 square feet, was completed early in 1966, and construction was started on a two-story office-laboratory addition to the Vehicle Assembly Building, scheduled for completion in January 1967.

The Sterilization Assembly Development Laboratory (SADL), consisting of a laminar downflow, Class 100 clean room, a complete biological laboratory, and decontamination and terminal sterilization chambers, was completed during the year. SADL will be used to make studies and develop the technique required to fabricate and assemble spacecraft capsules so as to meet the planetary quarantine requirements established for Voyager-type missions.

The 25-foot space simulator was modified to provide a larger illuminated area of solar simulation with improved quality and collimation. This was accomplished by means of a spherical collimating mirror, 23 feet in diameter, aluminized in place by a JPL-developed process utilizing a single aluminum billet and an electron beam gun to vaporize the billet. The mirror is constructed of ribbed, pie-shaped aluminum sections welded together and then ground to the appropriate spherical contour. Improvements were also made in the cryogenic system and the central control system.

The first leg of a new primary east-west route across the Laboratory has been completed, with the balance of the work scheduled for next year. Plans were made to link the Mesa Antenna Test range to the Laboratory, and work will start on the road as part of the construction of a 1,000,000-gallon water storage facility on JPL property.

Development of a new 500-car parking lot has been started, and two helistop pads were constructed on the roof of the new Materiel Services building.

JET PROPULSION LABORATORY EXECUTIVE COUNCIL

W. H. Pickering, *Director*

A. R. Luedecke, *Deputy Director*

F. H. Felberg	*Assistant Laboratory Director—Technical Divisions*
F. E. Goddard	*Assistant Laboratory Director—Research and Advanced Development*
B. P. Huber	*Executive Assistant to the Director, Secretary to the Council*
J. N. James	*Deputy Assistant Laboratory Director—Lunar and Planetary Projects*
W. H. Padgham	*Manager—Personnel Administration and Supporting Services*
R. J. Parks	*Assistant Laboratory Director—Lunar and Planetary Projects*
E. Rechtin	*Assistant Laboratory Director—Tracking and Data Acquisition*
D. E. Sowle	*Assistant Laboratory Director—Financial Management and Procurement*
H. J. Stewart	*Manager—Advanced Studies and Arms Control*